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# A study of individual fatigue curves

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BY

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## -INTRODUCTION-

The purpose of this thesis, broadly stated, is to study and analyze curves of fatigue resulting from repeated, voluntary stimulation of certain, closely related muscle groups in the intact organism. Briefly, some specific considerations of the study are:

1. To summarize past work upon the nature of fatigue and fatigue curves.

2. To present evidence of the nature of fatigue curves in the integrated organism as a result of muscular work done under experimental conditions.

3. To compare the nature of fatigue curves with reference to different sets of muscles within a given individual.

4. To indicate possible reasons for the contour of such curves.

5. To indicate anything relative to individual differences that may come from such a study.

6. To indicate further implications of such a study.

Any detailed elaboration of the problem will be considered further in the introduction to the experimental section of the paper.

In 1914, Glick (23), in an unpublished thesis at Northwestern University, introduced an experimental technique for the measuring of muscular fatigue, which, so far as is known, has not been attempted since that time. In the same thesis, he also undertook to measure mental fatigue by means of a unique apparatus. An attempt was made to correlate mental and physical fatigue. Because the job was a large one, and the time was limited, enough data was not secured in either field to warrant adequate interpretations.

Written under the guidance of Dr. Glick himself, this paper endeavors to carry further the work on the physical side of the question alone. For reasons which will be explained later, recourse is made in this study to the same type of apparatus as was employed by Glick in the original study. A few minor variations in construction have been added by the author for the sake of easier manipulation of materials. In addition, one or two other pieces of apparatus are employed in carrying this study some steps beyond the original.

# A STUDY OF INDIVIDUAL FATIGUE CURVES

## I. SUMMARY OF PREVIOUS STUDIES IN THE FIELD OF WORK AND FATIGUE

The topic of work and fatigue is a study of the total functioning organism. Work and fatigue has to do with the operation of perfected reaction patterns or systems, and the conditions which raise or lower the individual's levels of performance. The organism is viewed as a functioning machine, and its output is measured in terms of certain arbitrary criteria, as speed, accuracy, energy-transformations, endurance, or work decrement. Like every other machine, the human organism operates in terms of certain general principles, an understanding of which is essential to the explanation of its performances in complex operations. A major part of the task of explaining the complex behavior is simply the recognition of these general principles when they are present.

In order to present an orderly picture of the development of these general principles in the field of work and fatigue by various investigators of the past, a topical arrangement of material is preferable. The writing in this field is so varied and voluminous that a chronological presentation is almost impossible.

### 1. CONCEPTS OF WORK AND FATIGUE

The physicist tells us work is done when force moves mass against resistance, or when energy is transformed from one form into another. Certainly all productive operations of the integrated organism require energy transformations, but there are other factors of such operations that are equally essential. Memorizing poetry, studying philosophy, or solving problems ordinarily involve energy-transformation by hypothesis at least. But as Dodge (13) says, "Even if at some future time a mechanical interpretation of mental life might conceivably become a working hypothesis, at the present time such a hypothesis would be utterly barren and misleading." This statement does not mean that there is nothing mechanical about mental work, but it does mean that mental work requires much more than the principles of mechanics for a full understanding.

A distinction has commonly been drawn between mental and muscular or physical work and fatigue. A cursory examination will indicate that no clear cut distinction is possible. Thorndike (61) defines mental work as work involving the connecting system as opposed to muscular work involving muscles and sense organs. But obviously this is an abstraction, for no task is exclusively confined to the connecting system, and neither is any task exclusively muscular. This criticism does not mean that the common sense view of the man of the street who makes a distinction between such activities as golf, juggling and motor-car driving, and those involved in learning poetry, problem solving, etc., is unsound. The point is that there is considerable overlapping. Typing is a motor skill, yet it depends upon mental knowledge of reading, spelling, and rules of grammar. Watson (69) distinguishes between work of the gross and work of the finer skeletal muscles. Thinking or mental work is different from physical work in that it utilizes the finer vocal muscles. Disregarding the fact that the distinction is based on a purely theoretical assumption regarding the nature of thought, there are still very few mental tasks which exclude gross muscular work. Witness again typing, or the writing of this article. The distinction, then, between mental and physical work seems to be one of degree; the former involving relatively more use of the nervous system, and the latter involving relatively more use of gross muscles. It would be awkward to avoid all use of the terms, "mental work" and "physical work", but it should be recognized that their application is for purposes of ready description and it implies little or nothing about underlying processes.

Fatigue has been defined as "that loss of efficiency as a result of continuous work which can be eliminated by rest" (Bills (6)). Some studies of fatigue have defined the term subjectively as observed feelings of bodily weariness, ennui, boredom, or dissatisfaction with tasks. Objective studies, however, have concerned themselves with changes in level of performance or output as a result of continuous work; or with the physiological changes within the organs as constituting the real basis for fatigue.

Whipple (74) characterizes the opinion of many nicely when he says "It is helpful to separate objective fatigue (Ermüdung), i.e., actual functional in efficiency, from 'weariness' (Müdigkeit), i.e., the subjective experience of ennui, loss of interest, or disinclination to work. Thus, it is weariness rather than fatigue which disappears when one's occupation is changed. . ." Thorndike (62) has sought to avoid the loose usage of the term, fatigue, by defining it in such a manner as to limit it to the work decrement. By "work decrement" is meant that loss in efficiency which is typically produced by prolonged and highly continuous performance of a set task. Dodge (14) distinguishes between fatigue and <u>relative</u> fatigue according to the underlying causes of the decrement. As a result of these discrepancies in delineation, some psychologists, notably Watson (69) and Musico (44),have argued that the term, fatigue, is pseudo-scientific, and should be abolished from discussions because of its ambiguity. Certainly there is no entity fatigue which is independent of these various criteria, but the term is so well established that it seems more practical to use it with careful definition of exactly what is implied, than to try to eliminate it. In this paper, the term will be used in the sense of work decrement resulting from prolonged continuous work, and which can be overcome by rest alone.

It is hoped that this section will help untangle the knot of technical terminology involved in employing the terms, mental work, physical work, and fatigue, and will indicate, once and for all, the implications of these terms in this paper. The rather lengthy discussion of mental vs. physical work is intended for the layman who asks so many times what a study of muscular work has to do with psychology. The point to be emphasized is that the study of work and fatigue is a study of the total functioning organism, and as such involves an overlapping of functions making it impossible to discriminate nicely what is mental and what is physical in nature; what is for the physiologist, and what is for the psychologist.

## 2. MEASUREMENT OF FATIGUE, AND WORK CURVE PHENOMENA

In attempting to study scientifically the phenomenon designated as fatigue, investigators of the past have resorted to numerous methods. The most direct measurements of total energy transformations during integrated activity have been in terms of carbon dioxide production and oxygen consumption. The most successful studies of metabolism during work, (such as those by Benedict and Carpenter (3) in 1909, and Benedict and Cathcart (4) in 1913) have dealt chiefly with activities involving the use of relatively large muscle groups. Walking, running, climbing and bicycle-riding have been among the activities studied.

Dodge (13) cites changes in pulse rate and respiration as other important findings in connection with the operation of large muscle groups. In fact, these changes have been taken as reliable indicators of the organism's performance. In some investigations even alterations in body temperature have been accepted as indicators of energy-transformation.

Other studies have been based upon changes in production as measured in kilogrammeters of work, in seconds per task performed, or in psychological units of accuracy (e.g., correctness of arithmetic problems done over a period of time). The activities employed under this head are numerous and varied. Those studies of changes in production utilizing the hand dynamometer and the ergograph are of paramount interest in this paper. A more detailed account of such work will follow later. For the present, it is sufficient to indicate briefly some of the other tasks that have been investigated under this category of changes in production.

In 1908, Wells (72) investigated the normal performance in continuous finger tapping over 30-second periods. Now tapping is a type of work done at high speed against very little resistance. It is interesting to note from his work curves that they rarely show complete fatigue. During the early periods there is a decrease in speed until the worker reaches a point when he can perform almost indefinitely without exhaustion. Robinson (52) seems to think this phenomenon is true in all curves representing muscular work done at high speed. Robinson presents evidence from one-, two-, and three-finger typing as work of a more integrated nature which indicates this same trend in the work curve.

Some types of work involve control of movement. One of the best illustrations of fatigue in the control of movement is given by Dodge (15) in his records of eye movements. Some of the more characteristic fatigue phenomena which this study shows are : (1) speed of movement becomes less toward end of series; (2) fixations are less accurate; (3) and finally, the line of movement itself becomes more irregular.

Robinson and Bills (53) report a study of fatigue in control of movement where the size of writing increases when simple letter groups are written again and again at maximum speed. These curves of fatigue in controlled movement are very similar in contour to those for speed of movement. A fairly sharp initial decrement is followed by a more gradual loss of control. What seems to be the case in the continued writing is that the larger muscles of the arm have crept into activity as the more finely organized group becomes fatigued, hence the increase in size of letters. An interesting side-light is that the writing of young children strongly suggests the continuous writing of adults.

Leaving the realm of muscular fatigue to survey the realm of mental fatigue, one finds the literature full of activities which have as their outcome some intellectual task such as the solution of problems, color naming, judging distances, etc. It is interesting again to note that even in this highly integrated activity the curve of fatigue is typical of that obtained in speed of movement. The work of Chapman and Nolan (10), for example, in studying speed of mental arithmetic again illustrates the tendency of the worker to fall off rapidly to a level of efficiency which is maintained for an indefinite period. Even the classical experiment of Arai (1) in mentally multiplying 4-place by 4-place numbers illustrates this principle. In her case it took at least six hours to reach a level of continued efficiency, but the final attainment of this level is evident in her work curve.

Up to now, the discussion of changes in production has lead to a consideration of a gradual hierarchy of integrated activity, and the nature of the fatigue curves in such activity. So far, the foundation principles for this hierarchy in simple muscular work have not been laid. The study of work and fatigue of simple muscles and simple muscle groups in the intact organism has been approached in the past through ergography, or by making use of the hand dynamometer. The ergograph is an evolutionary product of von Helmholz's early myograph. When von

Helmholz wished to show the loss of energy in a wearied frog muscle as the result of fatigue products produced during work, he constructed an instrument called the myograph. A nerve-muscle preparation of the frog was hung upon a support. To the end of the muscle a lever was attached which came into contact with a revolving cylinder covered with smoked paper. With the frog's leg at rest a straight line was recorded on the drum. When the muscle was electrically stimulated, it contracted and the force of the contractions was measured by the height of the marks on the cylinder. As the muscle tired, the contractions grew smaller and smaller until the lever registered no mark at all.

Acting upon suggestions inherent in the myograph, Mosso (43) constructed the ergograph to record work done by a particular muscle or group of muscles in the intact human body. The chief point aimed at in the construction of the instrument was to isolate the working muscle or muscles as completely as possible so that no other muscle could be in a position to aid the tested muscles when they tired. The apparatus was arranged so that one part held the arm, hand, and all the fingers in a fixed position, except the middle finger which alone was capable of extension and contraction. This finger was required to raise a weight of from 2 to 6 kilograms by flexing in the ordinary manner. The results were recorded on a revolving kymograph in much the same way as were the markings of the myograph. An apparatus of this type is still widely used today, and has been the means of securing valuable information concerning muscular work.

Another instrument not so frequently used at the present time for measuring muscular fatigue is the Smedley hand dynamometer. Its original purpose was intended to be a measurement of the strength of grip of one hand. To measure fatigue it may be used employing continued or intermittent grip, but the latter method is generally more satisfactory. A modification of this instrument and a modification of the ergograph (to be explained later) was used in the experimental study reported in this paper.

In speaking of simple muscular work, it is quite impossible in the integrated organism to confine work to the operation of members in a definite muscle group and expect these members to remain in constant relationship to each other during the operation. Many investigators have avoided the ergographic technique for these very reasons. Yet there has not been substituted for study any other integrated activity entirely devoid of the variability inherent in the weight-lifting or spring-pulling of ergography, and as Robinson (52) says, "The ergographic method suffers when it is thought of as an attempt to study in the living individual the type of phenomena observable in the recurrent or continuous stimulation of the nerve muscle preparation. If the method is considered as another approach to the activity of the intact and living organism, its lack of simplicity may be thought of as a merit rather than a deficiency." Even if the ergographic pattern is persistently variable, there seems to be better hope of explaining this variability than in trying to understand the variations in tapping, mental arithmetic, or distance judging.

After the early enthusiastic investigations of Mosso (43)(1904), Lombard (38)(1887), and others, ergography went into a slump largely because of a skeptical attitude. Lately there has been a renewed interest on the part of the psychologists as is evidenced by the contributions of Crawley (11)(1926), Weinland (71)(1927), Manzer (41)(1927), and Yachelson (78)(1930). These studies have employed contractions of the single finger, of the hand muscles involved in grasping, of the flexor muscles of the arm, of the flexor muscles of the leg, and of the large muscles of the trunk as they are used in rowing. None of these later studies pay much attention to the specific muscles involved, nor are they as concerned in strictly isolating the working muscle or muscle group as were the early investigators such as Bergstrom (5), Ash (2), and Mosso (43). At the present time, it is still next to impossible to study in isolation a simple muscle or muscle group in the intact organism, with the expectation of constant conditions and non-interference of other closely related groups, in spite of stops, straps, clamps and other devices.

Yochelson's ergo-grams (78) exhibit phenomena characteristic of work done at a constant and moderate speed against heavy physical resistance. There is always a complete decrement, as far as objective performance is concerned, within a very short period. Of course, since the weight-lifting technique was employed, zero performance would not mean complete exhaustion. If a lighter weight were added at the last lift, the subject could go on for another period. One must admit (as Crowley (11) and others have experimentally shown) that adequate incentives might also stretch out this apparent "dead-end". There is some interest in comparing the decrement secured by ergographic and dynamometric work with that of the more integrated movements, such as speed of unresisted movement, controlled movement, and intellectual work. The most striking difference is that with the ergograph and dynamometer there is almost always a complete decrement, while in the other cases there almost never is a complete falling off. With the ergograph and dynamometer the subject does not unconsciously drop to a level of efficiency which he can maintain indefinitely. Especially is this true of the spring ergograph where the subject must pull at his maximum all the time. The weight ergograph allows for long periods of continued performance at a fairly constant level if the weight is too light in the first place; or if a considerable amount of high-level work has been done the subject may also shorten his lifts for an indefinite period. But the initial drop in the <u>early</u> period to a constant level of efficient performance is almost never present in any ergography. As Robinson (52) says, "The answer probably lies in the fact that in ergographic work the subject is given a definite standard and rate of performance, any departure from which he can easily detect. He therefore resists any tendency which might be present to let his level of efficiency drop until the occurrence of the drop can no longer protect him against the final and complete decrement. In such activities as tapping, the subject has a much less definite basis of judg-

judging his own performance. His efficiency can therefore slip off the required amount without meeting any great subjective resistance."

Then, too, Yochelson's ergograms represent typical performance pictures of particular subjects. Mosso early recognized that the decrement in ergographic work is a function of the individual. But later writers have been prone to speak of the typical fatigue curves just as they have talked about typical learning curves. Even Howell (32) in his "Textbook of Physiology" presents a curve from Moggiorpi which he labels a "normal fatigue curve". The variations in Yochelson's ergograms are important in that they suggest that the causes of decrement in muscular performance may not be due simply to energy depletion or accumulated fatigue products. The curves were obtained from subjects who had considerable practice under these particular experimental conditions, and each curve is a type for a particular subject. The study extended over many days, and, after a degree of irregularity during the early periods had passed, each subject was able to produce his own typical curve with very little variation from day to day. Experiments utilizing different muscle groups of these same subjects seemed to indicate that the curve remained fairly constant for a given individual. The curves might be said to be personality traits. Many investigators regret that these psychological factors must color and complicate the problem of decrement in muscular work. They look upon these factors as in the nebulous realm of the unscientific which cannot be measured but which unfortunately must be accounted for. Yochelson at least hints that the underlying factors, even though complex, are quite definite. Erratic individual curves suggest that in work of this nature a complicated system of activity is maintained, the balance of which is susceptible to disturbance. Simple expenditure of energy is not the whole story.

Of recent years, the hand dynomometer, as an instrument employed in fatigue studies, has disappeared from the scene to be replaced by the weight ergograph for the most part. In a way, the passing of the dynamometer is to be lamented. The dynamometer gives an isometric record of the contraction of the flexors of the fingers. In the better measurements of muscular contraction (especially is this true in working with isolated nerve-muscle preparations) the isometric records have been preferred to isotonic measures. "When a muscle contracts against a constant load which it can lift the contraction is spoken of as isotonic. . .If the muscle is allowed to contract against a resistance too great for it to overcome - a stiff spring, for instance - it is practically prevented from shortening, and such contraction of this kind, in which the length of the muscle remains unchanged, is spoken of as an isometric contraction." (Howell (33)). An early modification of the usual hand dynamometer for the study of fatigue is reported by Cattell (9) in 1897. The description does not come with the report. It is simply disclosed that the instrument was fitted to write upon a kymograph and the pressure of the thumb and forefinger as well as the movement of any finger could be measured.

Nothing very illuminating can be gathered from the early studies with the hand dynamometer other than an inkling of the methods employed. Two methods were common - the method with continuous contraction, and the method with separate contractions. In the former case, a metronome would be set to beat once a second. The subject was instructed at the signal, "now", to grip as forcibly as possible and maintain this grip with the utmost effort until told to relax at the end of one minute. He was to watch the pointer and keep it as high as possible. The experimenter was supposed to take the first reading, and one at every fourth beat of the metronome thereafter. With the advent of the improved Smedley dynamometer fitted for pneumatic transmission, a graphic record was secured on a kymograph by employing a pneumatic tambour and a system of levers. Objections to this method will be stressed in the experimental section of this paper. The method with separate contractions was somewhat similar. As the signal was given, the subject was to make a series of 16 grips as forcibly as possible at 4-second intervals. The experimenter took readings as previously. When the kymograph was used, the interval between grips was decreased to one or even one-half second duration.

Of the early investigators, the work of Binet and Vaschide (1897) reported by Whipple (75) is interesting but not too important. Using the separate contraction method upon a group of boys aged 10-13 and a group of young men aged 18, who gripped 5 times alternately with each hand, these authors noticed four types of endurance curves. These types represented: (a) a sudden drop, then fairly constant; (b) approximately stationary or constant type (which they thought quite common); (c) a continuous, but gradual drop; (d) and a more or less definite rise (this type infrequent).

It is hard to find any recent studies of note employing the hand dynamometer as a measuring device in relation to the work decrement. Glick's (23) unpublished thesis of 1914 indicates a new approach to the study. If it had found its way into the journals of the day, perhaps there would be more to report upon this phase of work at the present time.

True, other methods of studying fatigue have been attempted. There are various reaction time experiments all of which admit slower reaction at the onset of fatigue. The aethesiometric technique indicates the falling-off of the threshold of sensory perception at the onset of fatigue. Some investigators have employed the patellar reflex technique, pointing out the drop in the height of the knee jerk upon continued stimulation. All of these methods, however, are more or less side issues and do not come to bear upon the subject matter of this paper.

3. THEORIES OF WORK DECREMENT

As early as 1865 Ranke (49), a German physiologist, investigated the depressant action of certain products of protoplasmic activity upon muscular contraction. He demonstrated that if an extract of fatigued frog muscle be injected into a second fresh frog, the second animal exhibited fatigue. Extracts from a rested muscle had no such effects. About 1890 Mosso again showed that the depressing action of fatigue substances is not confined to the tissues in which they arise. He argued that the blood becomes charged with chemical wastes produced in working muscles and carries these wastes to all parts of the body. He arrived at these facts by fatiguing a dog in a tread mill and injecting the blood of this dog into the vessels of a fresh dog from which a similar amount of blood had been taken. The second dog showed signs of fatigue while injections from a rested dog produced no such effects.

It was such work by Ranke, Mosso, and others that led Weichardt (70), in 1904, to postulate the toxic theory of fatigue. In keeping with the medical trend of the time, fatigue became another specific toxin in the human system, analagous in chemical and physical nature to the long list of bacterial toxins. Weichardt claimed he had discovered a means of developing an anti-toxin which could be injected into a fatigued muscle and serve as an antidote for the fatigue toxin. He developed his theory experimentally somewhat as follows: Several large dogs were completely exhausted by pulling them backward on a rough surface. Upon chemical analysis of these animals, Weichardt discovered that the fatigue toxin was found in the muscle itself while the anti-toxin was found solely in the blood. When he extracted some toxin from the muscles of the dog and injected small doses of it into mice, the mice showed immediate signs of fatigue. When he injected the anti-toxin into the mice, the effects of fatigue disappeared at once. The reports do not indicate what criteria of fatigue were set up in any of these investigations.

While some hold the toxic theory to be fundamental, most workers in this field place little credence in it. The majority claim that the anti-toxin, if there is any, is nothing more than a tonic and has no lasting effects. A chemical theory of fatigue at present seems to explain the facts more satisfactorily, and it seems the part of wisdom to place more emphasis upon such a basis than upon doubtful toxins.

In order to fully appreciate a chemical theory of fatigue, a general outline of muscle chemistry, however brief, is a decided asset. The chemistry itself is closely allied with the energy changes in the form of heat and mechanical work of Hill (28) and Hartree (26) indicates that heat is liberated in two portions; one, the initial heat, is a sudden outburst at the beginning of contraction; the other, the delayed heat occurs after contraction and relaxation are over, during recovery. The initial heat is due to the chemical changes in the muscle liberated by the stimulus for contraction. This output takes place in complete absence of oxygen and hence must be a non-oxidative reaction. As will be explained later, it is believed that the dissociation of phosphocreatine into creatine and phosphoric acid furnishes the energy for the initial contraction and the heat liberated as initial heat.

The delayed heat depends in part upon the presence of oxygen. The delayed heat itself consists of two phases. One, the anaerobic delayed heat, appears at the end of contraction, and may be detected either in the presence or absence of oxygen. It is small in amount - about 8% of the initial heat. The second portion, or oxygen recovery heat, is much larger in amount, appears later, and requires the presence of oxygen. For the present it may be said that the anaerobic delayed heat represents a balance between the exothermic formation of lactic acid and the endothermic resynthesis of phosphocreatine. The oxygen recovery heat is interpreted as being due to oxidation changes - oxidation of lactic acid. Some endothermic reactions take place here also, the resynthesis of phosophocreatine and synthesis of lactic acid to glycogen, for example.

Today the chemical changes that occur in a muscle during contraction are more numerous, complex and less certain than they were to investigators fifteen or twenty years ago. The following reactions according to Howell (34) have been definitely established: (1) absorption of oxygen and formation of carbon dioxide; (2) formation of lactic acid from glycogen; (3) oxidation of part of lactic acid; (4) resynthesis of glycogen from part of lactic acid; (5) esterification of sugar and phosphoric acid to form hexose monophosphate; (6) dissociation of phosphocreatine into creatine and phosphoric acid and subsequent resynthesis of phosphocreatine; (7) hydrolysis of adenosin triphosphate with production of orthophosphoric acid, inosinic acid and ammonia.

It has been shown beyond question that lactic acid is formed from glycogen. As the acid increases glycogen decreases. The process in general is called glycolysis, but the nature of the reaction or reactions is not fully known. By enzymatic action glycogen changes to sugar, which possibly undergoes esterification with phosphoric acid and the hexose monaphosphate formed hydrolyses to some reactive form of hexose that gives rise to methyl-glyoxal and eventually lactic acid. The theory, at present, holds that about a fourth of the lactic acid is oxidized, and the chemical energy thus liberated is partly used to synthesize the rest of the lactic acid to glycogen again, the rest of the energy being dissipated as heat.

It is significant to note the change of theory in recent years. Once it was thought that the change of glycogen to lactic acid yielded the energy for the initial contraction. However, recent experiments by Lundsgaard (40) show that under certain conditions a muscle can give a long series of contractions without lactic acid formation. In addition, calorimetric studies show that in the initial contraction there is considerable excess energy liberated than can be accounted for in lactic acid formation. Lactic acid formation is now considered as occurring in the recovery phase rather than in the contraction changes.

The relation of carbon dioxide to the process of contraction is also interpreted differently now from what was formerly taught. The older observers thought that the stimulus set up an oxidative process which gave rise to energy for contraction and carbon dioxide production. The chemical change responsible for contraction is now known not to be oxidative at all, hence no carbon dioxide is produced in the initial period. The carbon dioxide which is so characteristic of the normal muscular contraction is held to be produced after the contraction is over by the oxidation of lactic acid in the recovery phase.

Several observers (Eggletons (17), Fiske and Subborow (18)) had called attention to the presence in the muscle of a compound of creatine and phosphoric acid, but its significance was not fully realized until the reports by Lundsgaard in 1930. He found that when an animal was poisoned by iodo-

-acetic acid it soon passed into a state of tense muscular rigor, but the muscles, instead of showing the characteristic large increase of lactic acid associated with rigor, showed no lactic acid beyond that found in the resting state. There was, however, as in all contractions, and rigor, a decrease in phosphocreatine. Since a muscle treated with iodo-acetic acid can give a long series of contractions with no lactic acid formation before it goes into a state of rigor, Lundsgaard concludes that the initial contraction energy does not come from the old oxidation of glycogen to lactic acid reaction, but comes instead from the breaking down of phosphocreatine into creatine and phosphoric acid - a non-oxidative process. Calorimetric studies now check on the energy liberated in initial contraction under this theory.

Another common reaction in the contracting muscle is the breaking down of adenosine triphosphate to phosphoric acid, inosinic acid and ammonia. The energy liberated by the hydrolysis of this compound is utilized to resynthesize the phosphocreatine.

In summary, the details and relations of this series of reactions in the muscle contraction have not been fully worked out - but the following schematic representation by Himwich (29) is probably as accurate a sequence as is available at the present time:

1. Phosphocreatine $\nearrow$ phosphoric acid, $\searrow$ creatine $\Big\}$ - plus energy for muscle contraction.

2. Adenosine triphosphate → phosphoric acid, inosinic acid, ammonia } plus energy for resynthesis of phosphocreatine.

3. Glycogen→Lactic acid + energy for resynthesis of adenosine triphosphate.

4. Lactic acid + energy from oxidation → glycogen.

The final point is to indicate the relation of chemical changes during contraction to fatigue. A muscle in continuous contraction soon fatigues; it relaxes more and more until it becomes completely unirritable. A physiological definition of fatigue, therefore, may be the more or less complete loss of irritability and contractility brought on by functional activity. But even in this state an interval of rest will bring about some return of irritability. The work of Ranke and others seems to have confirmed the view that the products of muscular metabolism, if they are allowed to accumulate in the muscle, serve to diminish or suppress its contractility. In all probability, so the theory goes, this effect is due to the acidity of the products formed, primarily, therfore, lactic acid. When muscular activity is prolonged under conditions of lessened oxygen supply some of these metabolic products do accumulate. When the need for oxygen under these conditions is so great that a sufficient supply cannot be furnished to oxidize the lactic acid even with increased respiration, lactic acid heaps up in the muscles and is given off to the blood. To use Hill's expression, the muscles accumulate on oxygen debt. In moderate exercise the oxygen supply is sufficient but as the exercise becomes more strenuous its inadequacy is evident by the rise of acid in the blood. When this substance accumulates in the blood it may affect the activity of other organs. Hence, in ergography this supposition may be used to explain the fact that marked exercises of the legs, for example, may diminish the amount of work obtainable in other unused muscles - those of the arms, for instance.

Lee (36) has published experiments indicating that the first effect of so-called fatigue substances is to increase irritability of the muscle, while the later effect is to diminish or suppress irritability. In this initial favoring influence, Lee finds an explanation of the phenomenon in work curves known as Treppe (explanation later).

The decrease in total work-power of a muscle after exercise is due to the fact, so the theory continues, that the energy-yielding material, phosphocreatine, has been depleted; the process of restoration has not kept pace with consumption. There is, then, real exhaustion of the muscle. The immediate cause of the loss of irritability designated as fatigue refers mainly to accumulation of lactic acid. Fatigue may very well develop (and most often does) while the muscles still contain energy-yielding material. Even such heavy muscular work as that involved in ergography develops a decrement probably before there has been anything approaching an exhaustion of the glycogen necessary for the performance of such work. This is shown by the fact that a relatively slight increase in incentive will ordinarily permit the subject to continue far beyond the point at which he ordinarily suffers from complete decrement. From the studies in the Yale laboratoy, Robinson (52), among others, subscribes to the idea that the exhaustion of energy-producing materials is a rare causal factor in work decrements.

Many writers have been aware of the fact that the causes of fatigue, or work decrement, run beyond the relatively simple factors involved in the chemical facts of exhaustion and toxicity. An outstanding attempt to formulate these other factors was made by Dodge (14) in 1917. Thorndike (63) stressed the importance of "satisfyingness" and discomfort as affecting the work curve. The results of Poffenberger's (47) experiment upon the relation between feelings and output show a steeper and prompter decrement in feelings than in actual production. Robinson (51), following Dodge's lead, formulated seven principles of work decrement, over and above exhaustion and toxicity, which he substantiates by experimental data and emperical observation. Most of the experimental background for these principles is definitely in the field of mental fatigue, so that it will not be considered in detail. It will suffice to indicate where these principles may apply in ergography and to make reference to the experimental literature. Like Dodge, Robinson also states his principles in terms of stimulus and response.

Principle I: The work decrement of a given S-R (stimulation-response) connection is relative to the recency of the previous functioning of that connection.

This is simply the familiar law of refractory phase. Historically, according to Verworn (68), the phenomena was first noted in heart muscle. Since then it has been found in striped muscle, nerve trunk and reflex arc. "Refractory phase" simply implies the general functional fact that reactive tissue and tissue systems (regardless of chemical basis) are resistant to early restimulation. Hence, in ergography, if the succeeding contractions follow each other too closely in time there will be a decrease in height of contraction because the muscle-nerve system has not had time to recuperate (electrically and otherwise) from the preceding stimulus. Dodge (15) has suggested that the relative refractory phase may be applied also to the more elaborate mental processes. Investigations of the refracory phase as applied to the associative processes have been undertaken by Thorndike (64) in 1927, Garett (20) in 1922, and Telford (59) in 1931.

Principle II: The work decrement of a given S-R connection is relative to the <u>frequency</u> of the previous functioning of that connection.

Simply stated the more homogeneous the work, the quicker, as a rule, the fatigue because of repetition of the same thing over and over. This principle brings out the added point that refractory phase is accumulative. After a connection has been exercised a great number of times it may reach a breakdown in functioning or prolonged refraction. The phenomena of contracture or "holding" effect (to be explained later) in ergographic work curves is a good illustration of the second principle. The relationship between heterogeneity of work and the work decrement has been attacked experimentally by Robinson and Bills (53) and Poffenberger (48). Before discussing the third principle, there is an interesting point about the fatigue curve which is often overlooked. Fatigue curves and learning curves are plotted on the same coordinate system - one axis representing efficiency, and the other frequency of repetition. Several writers (Dunlap (16), Köhler (35), and Thorndike (65)) have recently taken pains to point out (especially in learning) that greater frequency does not always mean increased efficiency, but that frequency of repetition may even bring about a decrease. The very existence of a fatigue curve with its accumulative decrement proves the case precisely, and also indicates that it should have been recognized as commonplace by experimentalists long ago.

Principle III: The work decrement of a given S-R connection is relative to the connections existing between that S and other R's.

This is the principle of competition. In many types of work, the decrement may be due to the competition of several outlets for the same stimulus. The factor of competition, however, does not function apart from recency and frequency. Robinson and Bills (53) tried to isolate the competition effect as much as possible in a study of one, two, and three finger typing. The decrement in speed was about as great for the heterogeneous work (two and three fingers) as for the homogeneous work (one finger). When these results are compared with the studies under Principle II, there seems to be a conflict. All previous studies indicate less decrement for heterogeneous work. The investigators conclude that in the typing experiment the decrement was because of the competition factor. Could it not be possible that typing with any of the fingers still constitutes homogeneous work, hence the equal drop?

Principle IV: The work decrement of a given S-R connection is relative to the strength of that specific connection.

Obviously this principle is meant to work in conjunction with the competition factor. The weaker the connection the easier it is won over in competition, and the quicker the fatigue. If the connection is strong, fatigue sets in later. While this principle may be sound logically, the experimental support by Glaze (22), and Robinson and Robinson (55) seems weak and far-fetched.

Principles V and VI (They are so much alike that a combination may be justly made.) The work decrement of a given S-R connection is relative to the <u>quantitative constancy</u> and <u>qualitative integrity</u> of the S throughout the work period.

Perhaps the most obvious example of this principle in operation is in the heavy muscular work of ergography. Kinaesthetic stimulation begins to change in the early stages of the work - one "senses" fatigue setting in as the voluntary stimuli get weaker and weaker. Decrement because of this factor is more likely to be true when the new elements among the operative stimuli act to arouse pain. It will be remembered that Thorndike emphasized occurrences of this type as the chief causes of decrement.

Crowley (11) found that subjects who watch their performance on the ergograph as it is being recorded on the revolving drum do more work - fatigue less easily - than subjects who cannot see the recordings while they work. Yochelson (78) found that the presence or absence of an audience also influences the worker.

Principle VII: The work decrement of a given S-R connection is relative to the decrements that have developed in other S-R connections.

This is the principle of transfer. It seems to be well established that if the decrement in one connection is profound enough, the transfer will be wide. As in transfer of learning, there is also the theory that transfer in fatigue depends upon presence of common elements. The study by Bills and McTeer (7) seems to indicate that there is some truth in this theory. The more elements there are common to a constant and alternate task, the more deleterious is the influence of the latter upon the former. That this condition should obtain, seems logical if one places any faith in Principle II which emphasizes frequency of repetition and homogeneity of work material - yet neither Robinson nor Bills seem to account for the decrement in this way. In fact, a broad interpretation of Principles I, II, and the combined V and VI seems to be all that is necessary to explain the phenomena of work decrement as it is found in experimental literature, i.e., over and above exhaustion and toxicity.

4. LOCUS OF FATIGUE

The problem of transfer of fatigue quite naturally brings up the question of locus of fatigue. As far as the exact localization of fatigue in specific parts of the organism is concerned, no one theory holds the respect of all investigators. In general, the chemical theory of decrease in existing necessary substances and increase in deleterious metabolites seems to be widely acceptable. But where the effect of this chemical process is first actually noticed is variously claimed for the peripheral organs, the motor end-plates, the nerve trunk, the general synapses, and the nerve center.

It was at one time thought that the isolated nerve trunk was relatively unfatiguable. Experiments of the following sort tended to strengthen the notion: Bowditch (8) in 1885 after applying the drug curare to a muscle to block the passage of a nerve impulse into the muscle so it would not be fatigued, excited the nerve several times a second for 5 hours. When at the end of this period the muscle had recovered from the drug, it responded by contracting when the nerve was stimulated. It is therefore assumed that the nerve had not fatigued but was still capable of conducting with undiminished energy. Nerve fibers, however, were found to fatigue from continuous uninterrupted electrical stimulation. Yet Harvey (27) in 1912 found that a trapped wave of neural excitation set up in a ring-shaped preparation of jelly-fish could course over the circular path as long as eleven days with no appreciable decline in rate. It was estimated that the wave travelled 457 miles in this time at a rate of about .5 meters per minute.

On the other hand with the recent evidence by Tashiro (58) and Gerard (21) emphasizing the metabolic and chemical changes as well as electrical changes in the passage of the nerve impulse, all things point to some fatiguability of the nerve fiber.

It has long been thought that the brain and spinal cord are much more susceptible to fatigue than the muscle, and since the evidence for fatigue in the nerve itself was negligible, many of the adherants of the neurone theory looked for the locus of fatigue in the cell body. The work by Hodge (30) and others indicate that excessive fatigue is accompanied by marked histologic changes. The Nisel substance undergoes a process of coagulation and is eventually absorbed. Since this substance probably functions in nourishing the cell, its behavior points to the metabolic nature of the change which fatigue causes in the nerve, as Tashiro and Gerard suggest.

Then again, Sherington denies central fatigue to the cell bodies and locates it in the synapse (point where one neurone comes in functional relation with next in series), and assumes that it acts, like the motor end-plate (point where neurone comes in functional relation with muscle fiber), as a safety fuse to prevent overwork and damage to tissues. However, pushing things off to the synapse always seems like avoiding the issue in light of our present knowledge about these functional linking points. Other experiments indicate that compared with the terminal organs, the reflex mechanism of the spinal cord is practically indefatiguable. If this conclusion is extended to the higher centers of the brain, a peripheral theory of fatigue is the next logical step. Prominent evidence against such a conclusion is found in the observations of Mosso (43) and Lombard (38) that a muscle exhausted by volitional effort will still respond to electrical stimulation. Mosso held that this phenomenon was due to the fact that the central nervous system was affected first protecting the actual responding mechanism, the muscle, from dangerous depletion. The same data was interpreted as showing that it was the motor end-plate that was affected since nerve fibers had been shown to be immune to fatigue, Lombard (38) and others have held this view. Hough (31), Woodworth (77) and Storey (57) all show that these muscles which were stimulated first to voluntary exhaustion, and those that were stimulated electrically were not the same muscles.

"In view of these results and others," says Lee (36), "I am inclined to the belief that when we perform continued muscular work, our muscular system fatigues before our central nervous system. Moreover, the same results make it probable that the brain and spinal cord are, like the nerve fiber, relatively resistant, and they throw a certain measure of doubt on all supposed proofs of central fatigue."

The question of mental fatigue induced by intellectual work, thus becomes perplexing. That it appears to be a reality cannot be denied. Very likely even this type of fatigue is largely peripheral in origin (i.e., due to eye strain, postural control, reduced metabolism, etc.), but how much is peripheral and how much central cannot as yet be stated. As with most knowledge, the status of this question regarding the locus of fatigue is one of flux. The fact that is quite evident from any discussion is that the nature of work and fatigue in the intact organism is far more complex than it would appear on the surface.

5. MISCELLANEOUS PHENOMENA

An analysis of work curves in general brings out certain other outstanding features which have not, as yet, been mentioned. One of these features, though not always present, is "initial spurt". The term itself seems to be a misnomer; the initial spurt can best be described as a high initial level of performance at the beginning of the work curve from which there is a rather sharp drop almost immediately. The point that needs to be explained when this occurs is not so much the early high point as the rapid dropping off which is actually an early onset of fatigue. Some investigators, notably Thorndike (60) and Reed (50) take the initial spurt as a chance variation or discredit it entirely. But there have been some studies devoted exclusively to the initial spurt phenomena which demonstrate its reality beyond question. Certainly no one holds that it is a <u>constant</u> feature of the work curve. What is needed is an analysis of the kinds of tasks and conditions under which it is most likely to occur. Chapman and Nolan (10) attempted to do this. Chapman points out that previous studies err in using too long units in dividing up the work period, so that initial spurt could not be seen if it were present. This criticism is directed principally at Thorndike's study in which five minutes were used as a unit. There is reason to believe that most of the spurt occurs in the first minute or two. In Chapman's study, the task consisted of the addition of columns of ten one-place numbers for ten ten-minute periods, with the work done at every two minutes marked by a check. The drop from the first to the second two-minute period exceeds that between any subsequent periods by more than twice. Phillips (46) and Morgan (42) also report decided initial spurts in curves of work involving such tasks as simple mechanical arithmetic and cancellation.

It is quite possible that the initial slump is caused by the rapid accumulation of associative interferences between the elements of the work involved. This interference would soon reach a maximum because with either numbers, cancellation, or colors named, the total number of possible elements to combine is soon exhausted, and beyond that point no increase in interference occurs so readily.

Other explanations of the spurt have been offered which may be applied to tasks which are not mental in nature to the degree of the illustrations cited. One attributes it to lack of motivation, that is, the rapid loss of zest, as the task progresses. It would seem, however, that such an effect should continue beyond the first few minutes of work. Another reason offered is that the subject starts off at a more rapid pace than he is able to maintain and the rapid drop is an adjustment to an efficient speed. One objection here is that before practice, when the subject is not used to the task, he ought to show greater initial spurts - but, unfortunately, this does not seem to be the case. Finally, there is the possibility that the initial high level represents a high degree of initial concentration of attention. Early attention is not maintained long; monotonous work soon carries over into a stage of semi-automatic control, and the individual carries on while thinking of other things. Any one or all of these explanations may be possible.

Another type of spurt is the "end spurt", consisting of a high final point at the end of a work curve which is approached rather abruptly from a preceding low level. While this phenomenon is supposed by some writers to occur only as the effect of an incentive when the individual is explicitly aware of the approaching end, it nevertheless occurs equally as well with subjects who have not been told how long to work or warned when the end was near. End spurts seem to be more prevalent among subjects who have worked a more or less constant amount of time on several successive days. Possibly the subject became vaguely aware of the time interval passed in comparison with the previous periods. The interesting thing is that spurts can occur after efficiency has fallen to a low level. It illustrates what available energy can be called upon by incentive or motivation. Here is also a good illustration what Dodge means by internal stimuli, and what Robinson (Principle V) means by qualitative integrity and quantitative constancy of stimulus - or change in stimulus strength.

A third interesting feature of the work curve is called "warming-up", a temporary beginning rise which disappears upon continuous work. Thorndike (61) thinks the importance of this characteristic of the work curve is exaggerated. He claims that from most of the data on the subject it is almost impossible to separate it from "the more permanent improvement that comes from the exercise of the function in general" that would ordinarily be called "practice" effect. Warming up in the work curve is similar to the so-called "Treppe" or "stair-case" phenomenon often present in the initial period when an isolated muscle preparation is stimulated continuously by electricity. Just what the phenomenon is physiologically can only be guessed at. It is recognized in all sports and physical activity where speed and accuracy are required. Baseball players, pianists, and typists all have warming-up periods. Lee (36) has suggested that the presence of lactic acid and other metabolites in small amounts is beneficial at first, leading to increased irritability, and that only excess waste products cause lowered efficiency.

It was thought possible to experimentally determine under what conditions this effect is most favorably produced, for, like initial and end spurts, it is not always present in curves. Robinson and Heron (54) suggested that one determining factor was a certain degree of discontinuity of performance. To investigate this hypothesis, the following experiment was performed: Twelve subjects tapped for either ten minutes straight without rest, or else they tapped five minutes, then rested a certain time, and tapped five minutes again. The length of rest periods varied from ten to one hundred and twenty seconds. The amount of warming-up was computed by determining the increased number of taps during the second five minutes over the first five minutes and subtracting from this warming-up, the practice effect which persisted to the next day's work. The results show an absence of the warming-up effect for the conditions with zero, ten, and twenty seconds rest, and the presence of warming-up for conditions with forty, eight, and one hundred twenty seconds rest. It was concluded that the relative discontinuity of the last three conditions enabled the effect to appear, which was otherwise concealed by fatigue in the first three conditions. In spite of this attempt to find scientific backing for a belief, the fact that unpracticed subjects often exhibit the warming-up effect in their very first curves is not yet explained. Wells (73) and others, however, support the findings of Robinson and Heron. The reason why warming-up does not appear without sufficient discontinuity between work periods has been ascribed to the highly continuous nature of the work which gives maximum advantage to the decrement (Robinson's Principles I and II). If the effect will appear in the second period after some short interval of rest, and if it is more pronounced, the longer the rest intervals between periods, why does it not appear in the first period when the rest period before attempting the work for the day has been much longer? The experiments and explanations by Robinson and others on the basis of discontinuity, seem too shallow, somehow, to sit well as solid food for thought.

A fourth effect that is often prevalent in work curves of the larger muscle groups, such as those employed in gripping the hand dynamometer or in ergography, is "holding", or retarded relaxation. Some subjects find it impossible to relax their muscles completely between each grip or pull on the instrument. The effect is very similar and perhaps identical to the state of contracture that appears when an isolated muscle is stimulated repeatedly. In contracture, the muscle upon shortening to one stimulus does not lengthen completely before it shortens again in response to the next stimulus. Contracture, in some cases, develops at the beginning of a series of contractions as was the case when it was first observed by Tiegel (66). In other cases it appears later on in the curve preceding or following the development of a state of fatigue. When the condition develops early in the functional activity of the muscle, further activity usually causes it to disappear, and the condition of the muscle as a mechanism for prompt shortening and relaxation is improved. When the contracture appears late in the series of contractions it is usually permanent and wears off only as the muscle relaxes slowly from fatigue. In some cases it persists until fatigue puts an end to any contractions whatsoever.

When the work curves obtained from a spring ergograph or a dynamometer are examined, in many instances, it is evident that something akin to contracture is taking place. The type or amount of "holding" exhibited under these conditions will vary from individual to individual. Some subjects evidence complete relaxation, i.e., each individual pull or grip begins exactly at the base line. With the majority of individuals, however, there seems to be a tendency to "hold" more and more especially toward the end of the work curve. This means that the muscles involved are not relaxing between grips, and each succeeding grip starts at a point higher above the base line than the preceding one. Other subjects may "hold" high to begin with and relax more as they fatigue, but this reaction seems rare. Some individuals are erratic - "holding" at one time and relaxing at others - and other individuals exhibit an even amount of "holding" which may set in early and continue to the end. More will be said about "holding" effect in the experimental section of this paper where "holding" curves will be presented to illustrate the various points mentioned above. What seems to take place is the gradual fatiguing of a part of the muscle group in operation so that an early state of tonic contracture renders some members of the group relatively functionless. The other members still carry on the work - but the mechanism as a whole is unable now to relax completely. And as these latter members also reach a state of contracture, less and less relaxation occurs until the muscle group ceases to function at all.

All this, of course, is more of a description rather than an explanation. A recent attempt to explain contracture may have some bearing on the subject of "holding". From the physiological standpoint, the phenomenon of contracture when compared with that of simple contraction processes may take place in the muscle, one involving the state of tone, and, therefore, length and hardness of the muscle, the other controlling the quick changes in length. This suggestion has been made by a number of authors, Guenther (24) among others. It has been suggested by some (Needham (45) and Denney-Brown(12)) that there are two different kinds of muscle fibers in each muscle (white and red), one giving a usual quick contraction, and the other responsible for a slower contraction which exhibits itself as tone or contracture.

Acting upon this last lead, it may be possible to explain "holding" as an effect due primarily to the very difference in function of red and white muscles in the muscle group involved. It has been observed that red muscles, in general, are less susceptible to fatigue and are found in those positions where long continued or sustained contractions are necessary. Histologically it has been stated that the fibers of red muscles differ from those of the white in being more granular and less distinctly cross-striated. The generalization has been made that the more evident cross-striation is an expression of a more perfect contractile mechanism, since, in general, white muscles show more rapid contraction. The generalization that <u>every</u> muscle contains both white and red fibers may not be entirely justified. At any rate, it may be that the white muscles of an active group fatigue first, and then the red - hence the interesting feature of "holding" in some work curves.

Enough has been indicated in all the foregoing discussion to serve as an outline of general principles. The following pages will deal with the more specific problem which prompted this piece of experimental research - namely the study of individual fatigue curves as they appear in different muscle groups and in different subjects doing the same work.

# II. EXPERIMENTAL INVESTIGATION

## 1. THE PROBLEM

A survey of the literature regarding fatigue curve phenomena is bound to pave the way for further questions and more problems. The first thing that will bear further scrutiny is the matter of a typical fatigue curve. The blanket term, "typical", is often made to cover more than it should. Does it mean typical for the group studied, for the task performed, or merely for the individual performing a set task? It has already been shown that the fatigue curve for rapid unresisted movement differs from that resulting from slower controlled movements, and both curves in turn differ from the curve resulting from sustained mental gymnastics such as multiplying four-place by four-place figures. But even when this point of difference is made, little has been said about the individual curves which make up these three "typical" curves for these three different tasks. Are these individual curves "typical" for these tasks also; or are there wide individual variations? Are the curves of any individual for a given task typical for <u>him</u>, however, - i.e., will he constantly give the same fatigue picture under approximately constant conditions? If he varies from his usual production, how can his variation be explained? Is it due to practice effect? Do other external influences such as the amount of sleep, meal time, excitement, previous activity, introspective estimates of his own strength and well being, etc., have any influence upon the nature of the resulting curve? How much of a personality trait is an individual fatigue curve? Is it any good as a personality indicator? Will the same type of curve appear in different sets of muscles doing relatively the same kind of work? One might well wonder also if the curve of physical fatigue for an individual approximates his curve of fatigue in mental manipulations. In regard to these individual matters, however, it is all too evident that one can draw little help from the past studies of group averages.

It was such individual problems as those just outlined that prompted the present study. The investigation was divided into two parts. First a study was made of the fatigue curves of the muscles of the forearm and hand utilized in repeatedly gripping a revised hand dynomometer, and secondly a study was made of the fatigue curves of the muscles of the middle finger pulling upon a specially constructed spring ergograph. The second study was selected because it involved a smaller yet relatively related set of muscles doing relatively the same type of work. Twenty-two subjects were employed in the first study, and thirteen of the same subjects participated in the second study. Conditions were kept as constant as possible. Before any records were taken all subjects underwent a practice period of two weeks duration in which they familiarized themselves with the instructions and got the "feel" of the instruments. This practice period in the majority of cases served to iron out some of the so-called "practice effect", but some of the subjects nevertheless showed constant improvement throughout the study period. Such a practice period was required at the beginning of each study period, i.e., before the subjects used the dynamometer, and again before they used the ergograph. Furthermore each subject came in each day (except Saturdays and Sundays) at a specified time, sometimes in the morning, sometimes in the afternoon, and, in the dynamometer study, at some time directly after eating - usually after the noon meal. At any rate each individual had his own daily schedule, and it was only rarely that two recordings were required of the same individual in the same day. If this was necessary because of the spoiling of a record in the process, for example, the next reading was not taken until at least four hours had elapsed so that there was ample time for recuperation of the muscle. The subject had to fill out a report each time of which more will be said later. As a rule, the subject was alone when he took his record with the exception of the investigator. Once or twice another instructor was present. Only in one instance was there a large audience present, and the abnormal results under this condition will be given special treatment later. In general, the subjects tried to keep their daily habits of eating, sleeping, etc., as regular as possible, but when any deviation from routine was made an observation to the effect was entered in the daily reports. The collecting of data covered a period of five months beginning in January, 1937, and ending sometime in the latter part of May of the same year. Some time was lost between the two study periods in getting the ergograph constructed and set up. Letting this suffice as a general description, it is best now to consider more in detail the apparatus used, the method of collecting data, the subjects participating, and the method of collating results.

2. APPARATUS

Early studies utilizing the hand dynamometer as an instrument to measure endurance or fatigue, employed the old oval shaped instrument which fitted in the palm of the hand, or the larger Smedley Revised Dynamometer with or without pneumatic transmission. As Franz (19) points out in his excellent critique on the methods of estimating the force of voluntary muscular contractions, the dynamometer has an advantage over most instruments because it employs an isometric spring. When a muscle pulls against an isometric spring, the muscle does not shorten very much and the energy is converted mainly into tension. This very factor is a distinct advantage over the isotonic method resorted to in weight-ergography. In pulling against a weight, the muscle is continually lengthening and shortening, and these changes in extent of movement introduce another variable factor that should be eliminated if possible. This factor is the change of nutrition of the contracting muscle. When the movements are long, as in the beginning series on the weight-ergograph, a considerable amount of blood and lymph will be displaced about the muscle tissue. Circulation will be increased and waste products taken away readily. When the movements become shorter, as toward the end of the series, the circulation changes, waste products accumulate, and the condition of the muscle is wholly changed. With a constant extent of movement as is the situation in isometric contractions this difficulty will be reduced to a minimum.

Franz (19) objects to the oval dynamometer because too many muscles are involved, and because the instrument cannot be gripped in precisely the same manner two consecutive times. A slight shifting of the hand brings into action new unfatigued muscles, and other muscles are given a chance to recuperate partially. Such slipping of the oval dynamometer, due primarily to perspiration, is very apt to occur during a series of grips, so that the results are not strictly comparable. Length and contour of hands are so varied that it is almost impossible to keep the conditions constant using an instrument of this type.

In order to avoid these difficulties, Smedley marketed a new dynamometer which is commonly employed more as an instrument to measure strength of grip than endurance or fatigue. However, the early investigators meant it to be used for the latter purpose, and it served to iron out the faults of the oval instrument. There is less chance for the hand to slip when grasping this particular shaped handle of the Smedley instrument. In addition the handle can be adjusted to fit almost any size hand. As was mentioned once before, either the method of constant or intermittent grip was employed by the early investigators using this instrument as a measure of fatigue. The intermittent method was more often preferred but the operator ran into more difficulty than the subject did when this method was used. The metronome would be set at 60 (one beat per second) and at every fourth beat the operator would signal the subject to grip. He then had to read the dial, record the figure, reset the hand and get the subject ready for the next grip. Obviously the method was open to error in reading the instrument as well as allowing too much recuperation between grips for the subject,

Smedley then produced a revised dynamometer fitted with an attachment for pneumatic transmission. This dynamometer has a small aluminum tube attached in which a small piston head is tightly fitted. The aluminum tube is connected with a tambour by means of a small rubber tube. When the dynamometer is gripped, the piston head works in the aluminum tube and tends to create a vacuum in proportion to the force exerted upon the dynamometer. Naturally the vacuum effect is transmitted through the rubber tube and affects the diaphragm of the tambour. This in turn affects a stylus which records upon the drum of a kymograph in the usual way.

Such an instrument seemed to be the solution to the problem. Now all the operator had to do was to sit back and let the subject pull and the tempo could be stepped up to once or even twice a second. Glick (23), however, in 1914 found several outstanding faults which rendered the instrument as such unfit as an accurate measurement of fatigue: (1) A quick grip tends to create a greater vacuum and hence affects the stylus more than a slow grip of the same force. Some subjects are inclined to grip quickly and let go slowly, others do just the reverse,- so comparable records cannot be obtained for two such adverse individuals with such an instrument. (2) A strong grip affects the record more than a weaker one. For example, if a grip of 50 kilograms effects a throw of two inches, a grip of 20 kilograms may not effect a throw of more than half an inch. This discrepancy can probably be explained by the inertia, caused by the long throw, carrying the stylus beyond the point where force alone could drive it. (3) Possibly the greatest defect in this form of recording is its failure to register holding effects. Few, if any, subjects completely relax, and let the instrument come to rest between grips. This fact can be observed in Plate #4 on page 51. When the lines are traced to the hand it means that the grip was entirely relaxed, and the space untraced between the hand and the end of each line represents the grip held each time. (Instrument in photograph to be explained later). This grip which is held should be measured as well as that which is relaxed. The kymograph recordings do not measure the unrelaxed grip, and this fact alone may greatly disfigure the curve. If the subject completely relaxes at first and holds toward the end of his curve, his kymograph record will show a sudden drop. If the subject holds at first and relaxes last he will show but little drop. All things considered, the two curves might be quite similar, but one would never know from the kymograph recordings. Thus curves may be greatly influenced by this one factor alone.

Since this method of recording could not be relied upon, Glick (23) constructed an instrument of his own which was simply a revision of the Smedley Dynamometer with its faults eliminated. In the present investigation an instrument patterned after Glick's revision was used. A few minor details to make easier manipulation in recording were added, but the instrument is essentially the same as that employed by Glick. The Smedley Dynamometer itself appears on the market today as it was in 1910. Nothing has been done to improve its effectiveness as an instrument for the measuring of fatigue since Glick's study in 1914. The instrument is only occasionally used in psychological laboratories to measure the strength of grip. Yet, with a bit of revamping, it has inherent possibilities of becoming a good instrument for the measurement of fatigue.

In constructing the apparatus as illustrated in Plate

1 and Plate 2 on pages 47 and 48, the dial plate and loose hand were removed from an ordinary Smedley hand dynamometer, and the dial was replaced by a piece of sheet zinc 11 inches by 13 inches (a, Plate 1) backed by cork boarding to hold it stiff (a, Plate 2). An aluminum sheet would probably serve better. The instrument was not fastened to the center of the zinc since about 8 inches to the right and no more than 4 inches to the left are needed as may be seen by examining Plate 1. The fixed hand (b, Plate 1) was prolonged about 17 cm. by a small, thin-walled, brass tube about 4 mm. in diameter (c, Plate 1). The tube may be either soldered or fastened to the hand by screws. This tube was sawed open on the under side nearly its full length - all except about 3 cm. where it was fastened to the hand. This opening was about 1 mm. wide.

Filling the hollow tube was a small brass rod about 2 cm. long which was free to slide the entire length of the tube. To the underneath side of this rod was soldered a small, delicate spring stylus which projected through the slit in the under side of the tube. The stylus pressed against the surface of the zinc. When the instrument was gripped the long hand carried in an arc across the sheet for a distance proportional to the force exerted, just as the original hand was carried about the dial in the original Smedley instrument. If the surface of the zinc sheet were now covered with smoked kymograph paper, cut to fit and fastened with spring clamps (b, Plate 2), the stylus would leave a mark in the soot and indicate where the hand stopped.

The next problem was to have the stylus mark at a different place for each successive grip if the force for each

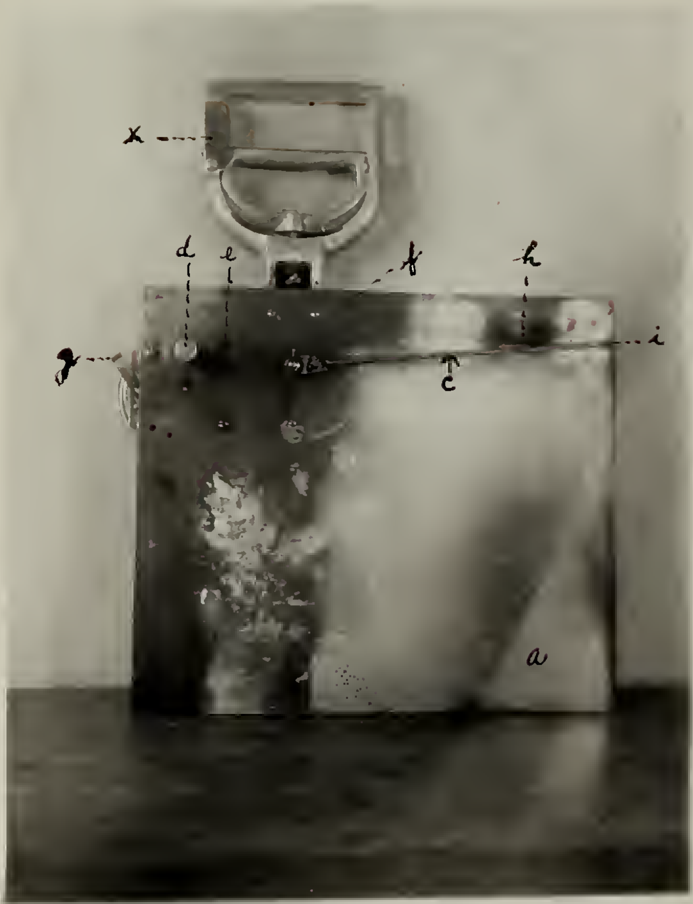



PLATE 1

Front View of the Glick Revision of the Smedley Dynamometer for Use in Measuring Fatigue.

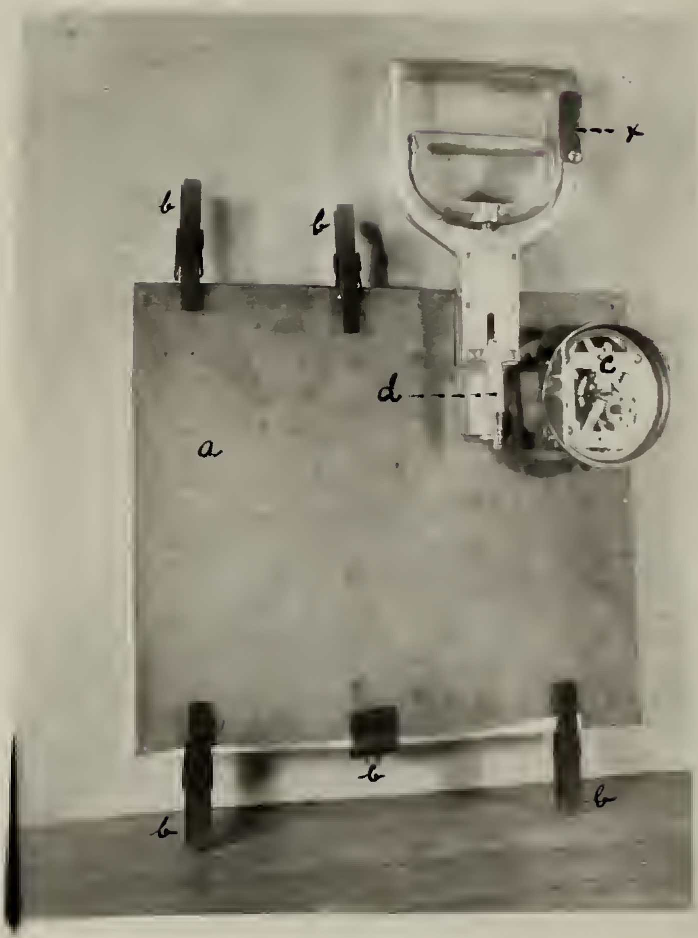



PLATE 2

Rear View of the Glick Revision of the Smedley Dynamometer.

individual grip was to be measured. The works of an alarm clock (c, Plate 2) were fastened to the rear of the zinc sheet. The shaft for winding the main spring was extended through to the front of the zinc sheet and keyed to a spool (d, Plate 1). This spool acted as the stem wind of the main spring when it was turned in one direction. From the side of the spool a small brass stud projected about which a loop of thread (e, Plate 1) could be slipped. The other end of the thread passed behind a peg guide (f, Plate 1), through the tube, and was fastened to the end of the stylus-rod. A lever (g, Plate 1) was attached to start and stop the alarm clock. Now if the clock were wound, the loop of thread attached to the stud on the spool, and the lever lifted, the thread would be slowly wound around the spool, and the rod bearing the stylus would be drawn in at an even rate, giving a fresh place for the stylus to mark each time.

A bumper (h, Plate 1) covered with soft felt was fastened to the zinc sheet for the hand to strike, for when it is let loose, it flies back violently. At the outer end of the tube (i, Plate 1) a small guide was fastened to run smoothly over the zinc surface and to keep the long tube from striking into the soot and spoiling the record. This guide traces the first heavy arc that is registered. Its course can be seen in Plate 1 where it has marked the zinc from constant rugging. Plate 2, d, indicates the aluminum tube of the Smedley dynamometer to which the rubber tubing and tambour would be attached for pneumatic transmission to kymograph recording. It is this method that this revised instrument is intended to replace. The catch (x, Plate 1 and Plate 2) is the point where the handle of the instrument may be adjusted to fit various sized hands.

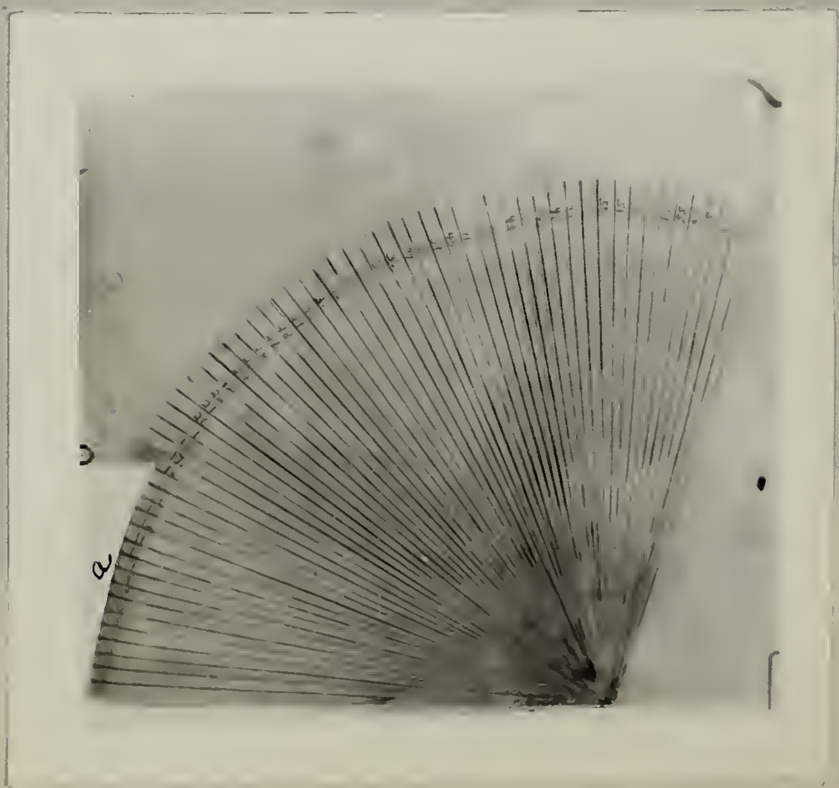
Now when a record is to be taken, the stylus is pushed (by means of a stiff wire) to the outer end of the tube. The string connecting the stylus-rod to the spool must be just long enough so that it will be stretched taut when the stylus is at the outer end of the tube. When this is done, the clock is started, and the gripping is begun in time with a metronome beating once every half second. The clock continues to run and the stylus is constantly drawn toward the center making a new mark on the smoked paper at each grip. A completed record is shown on the instrument in Plate 3, page 51. The string is kept taut all the time by the centrifugal force exerted by the rapid circular motion of the long tubular hand. The smoking of the paper was best accomplished by fastening the paper to the instrument first and passing the face of the instrument over an ordinary smoking lamp burning kerosene.

When the record is complete, necessary facts concerning the data such as subject's name, date, etc., may be scratched in with a wire or bamboo stylus. The record is unfastened from the instrument and run through a fixing bath of alcohol and shellac. One part of white shellac to five or six parts of alcohol will constitute a good bath - the proportion does not matter as long as there is considerable more alcohol (denatured) than shellac. The record is then hung up to dry, and is ready for handling in a short period of time.

In order to read the points of a work curve thus registered, a scale was constructed in kilograms from the original

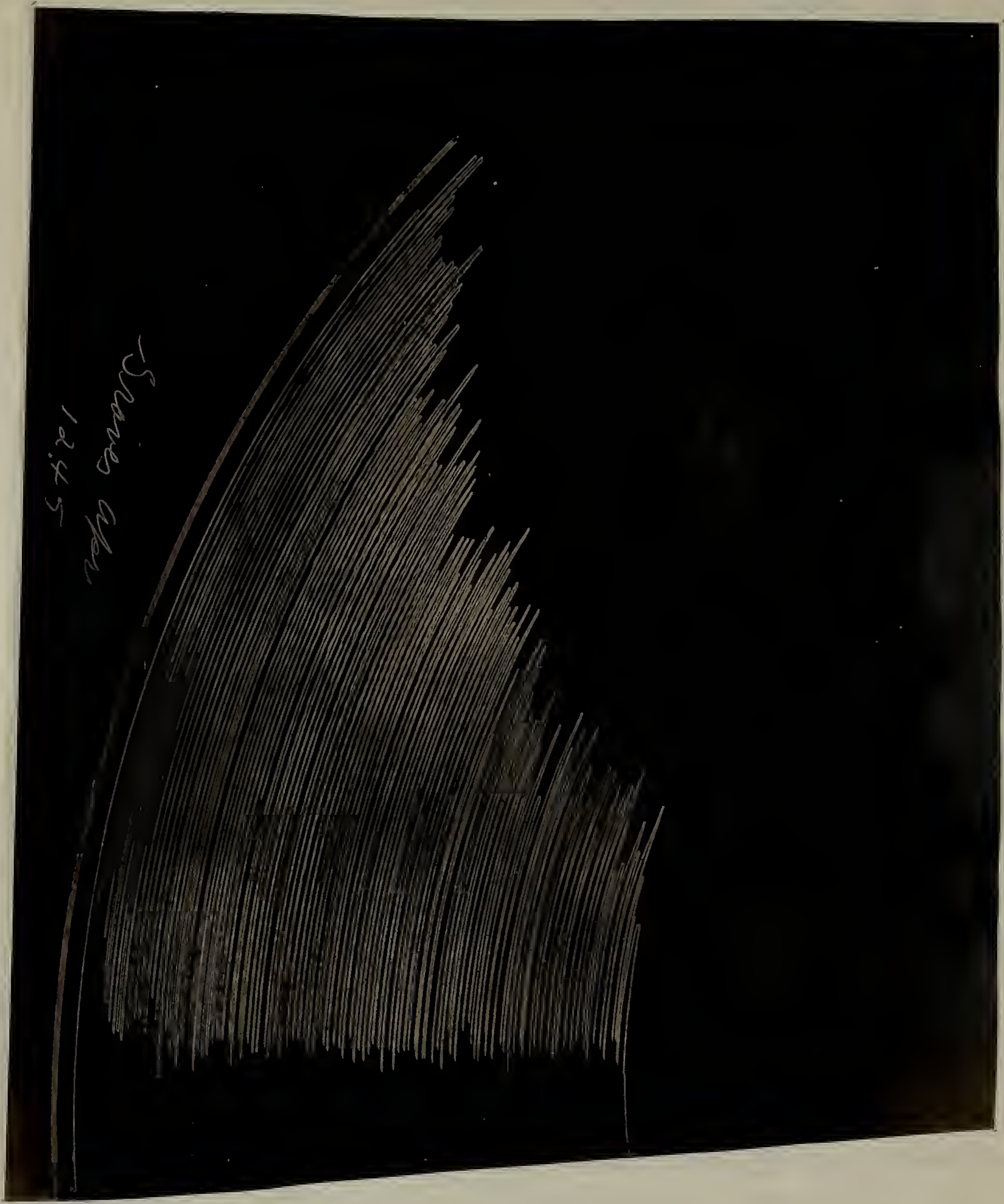
P L A T E  3

Revised Dynamometer With Completed Record



P L A T E  4

Celluloid Scale for Reading Records



P L A T E 5

Sample Record from Revised Dynamometer.
Note early high holding and gradual
leveling off.

dial on the Smedley instrument. This scale (Plate 4, page 51) was drawn on transparent celluloid with indelible ink. A glass etching, if possible to obtain, would have rendered the reading still easier. The record sheet was placed on a drawing board, and the scale was placed over it so that the base line, or bottom edge of the scale, coincided with the base line of the record, and the arced section (a, Plate 4) of the scale coinciding with the first arc on the record which was always traced by the guide at the end of the long tubular hand. A sample record with this heavy, outer guide line clearly defined is illustrated in Plate 5, page 52. The top points, as well as the bottom points illustrating holding effect, could thus be easily obtained in terms of kilograms pulled or held.

In the second part of this study a specially constructed spring ergograph was used. Various reasons prompted the use of a spring ergograph rather than the usual weight-lifting device of the Mosso type. With the Mosso ergograph, if the maximal contractions are repeated every two seconds, at first the extent of movement is great, but after from fifty to one hundred contractions the muscle can no longer raise the weight, and no mechanical work is accomplished. The total work, therefore, according to Mosso which a muscle can do before it is fatigued, is the product of the weight and the sum total of the extent of the separate lifts. But common sense alone calls to question the truth of this assumption. When a muscle can no longer lift a weight of, for example, three kilograms, and consequently under this condition does no mechanical work, can it not do <u>some</u> work? As a matter of fact, Treves and others have found that considerable work may still be done if a lighter weight is used. Indeed, a weight of two kilograms may, at that point, be lifted nearly as high or even higher than was the original lift of the three kilogram weight. Moreover, when a muscle pulls against a weight it cannot lift, considerable physiological work is being done even though no mechanical work is evident.

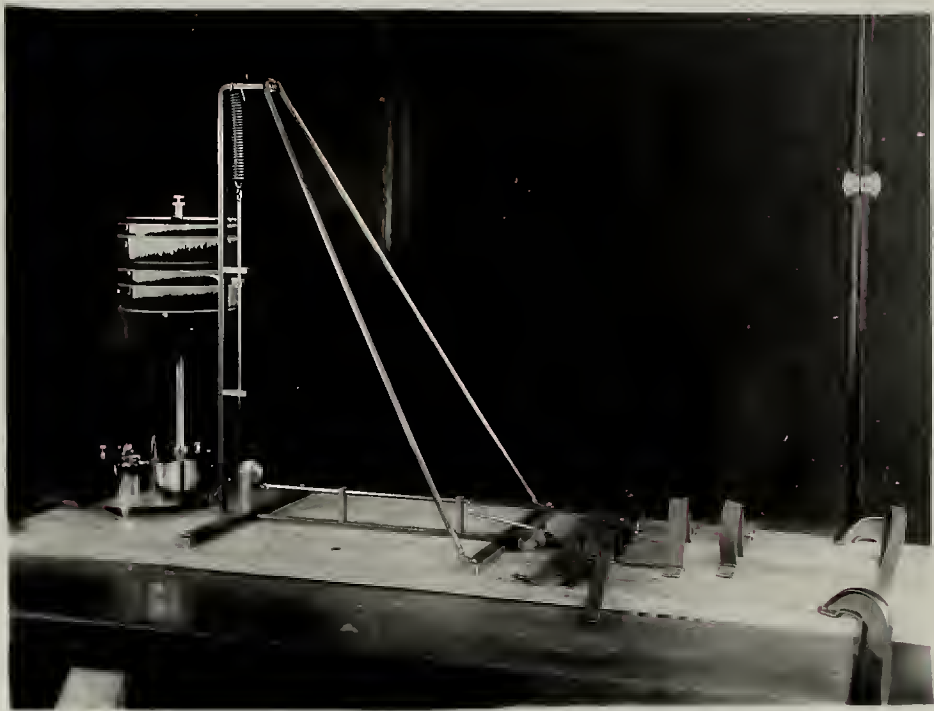
At the same time, weight-ergograph curves are hardly comparable even when two individuals pull the same weight until their finger muscles are exhausted. No two individuals have the same maximum pull to begin with. If a man is set to work who can just raise three kilograms to its highest level once, certainly the rest of the curve will show a decided downward trend. If another individual is set to do the same task but who can easily lift five kilograms, his curve will show a long series of lifts of even height before there is any indication of a drop. In fact, if one examines the usual weight-ergogram, there is nothing much evident in the way of a fatigue curve at all. Usually there is a long series of lines of equal height and about two or three gradually decreasing ones at the end. The end drop in most every case exhibits a decided, sudden dropping-off which would not occur in ordinary muscular fatigue. In addition, as has been already indicated, the weight ergograph has the disadvantage inherent in any isotonic method of measuring muscular force. The changes in extent of movement from the early contractions to those at the end cause a corresponding change in muscular nutrition, so that the condition of the muscle is wholly changed during the work period.

It was such objections as these that led Franz (19), Catell (9), Binet and Vaschide (75), and others to devise their spring ergographs. By pulling against a spring, the least muscular force can be registered, and maximum contraction of all individuals is permitted at all times if a stiff enough spring is employed. In addition, there is less chance for inertia effects to alter the height of the lift as is the case with weight ergography. The shape of the curve itself is more indicative of a fatigue curve than is any weight ergogram.

In spite of these advantages, to be entirely fair, one must also recognize the limitations of the instrument. The tacit assumption made by users of the spring ergograph that the tension of the spring is immaterial provided the tension constant is sufficiently great enough to register a maximum effort each time a contraction is made, is not entirely free from question. As Franz (19) demonstrated so well, if, after a series of contractions against the force of a heavy spring, a new series is begun with a lighter spring, it will be found every time that the work done with the lighter spring will be greater than that done by the heavy spring. At the same time, whenever a change is made from a heavy spring to a light spring, there is a decrease in the amount of tension overcome. In another experiment, work with a medium spring was alternated with work upon a strong spring. Sixty-six alternate work periods were run with ten-second rest periods between changes of springs. All results were the same, both the work accomplished and the tension overcome were different when different springs were used. In regard to the work done, it was found that some subjects did more work against the medium spring. The amount of tension overcome, however, was always greatest with the heavy spring. It would seem then that a change of tension in spring ergography creates a condition similar to a change in weight on the Mosso instrument.

The same criticism that was leveled against the weight ergograph in regard to the change in extent of movement from early to later contractions affecting a change in muscular nutrition, must also be held against the spring ergograph. It is every bit as much an isotonic measurement as the weight instrument. The ideal situation of course would be to get an isometric finger pulling device similar to a dynamometer. Since there are none of these on the market, recourse was made in the present investigation to a type of the spring ergograph, as the best means to attack the problem of measuring fatigue in the smaller muscle group.

Since the laboratory was not equipped with the horizontal kymograph which is necessary in using the ordinary commercial ergographs, a simple spring ergograph was constructed, adapted for use with the usual vertical kymograph. The simplicity of the device can be seen at a glance by examining Plate 6, page 57. The bare essentials consist of a six-inch wound spring, a supporting frame of heavy stock metal to hang the spring upon, a few connecting rods run through fixed guides, a ball-bearing pulley for mechanical advantage, a connecting strip of leather to run over the pully, a finger-piece, a pointer to write upon the kymograph, and straps to hold forearm and fingers. The upright piece supporting the spring is about 27 inches high. The first metal guide, through which a 12-inch, light, metal rod runs, is placed about 12 inches from the top of the metal upright.



P L A T E 6

Spring Ergograph Adapted for Use with Vertical Kymograph.

The next guide is spaced 8 inches below the first guide, leaving a space of about 7 inches to the base board upon which the frame is screwed. The 12-inch vertical rod, running through the guides, connects the spring to a leather strip which passes under a pulley. The other end of the leather strip is connected to another 12-inch rod which in turn passes through two metal guides. The entire metal base is about 18 inches long from front to back.

To the front end of the horizontal rod is attached by links a shorter rod of about 4 inches in length. This short rod in turn is fastened to a leather loop. The leather loop runs through the side walls of a single finger cut from a good-sized kid glove. The kid finger-piece was long enough to cover the tip of the middle finger, and extend down just below the first joint. This finger cap kept the leather loop from sliding down the finger beyond the first joint when the subject pulled. An elastic draw-string was placed around the opening to the finger-cap in order that it might fit more snugly the slender fingers of the women subjects.

A 4-inch bamboo stylus was fastened to a thin metal strip by means of flexible collodion. The metal strip was fastened to a small brass fitting which was free to slide up and down the vertical rod between the guides. The brass fitting bearing the stylus could be fixed at any point on the rod by means of a set-screw. It was found convenient to set it at a point just below the first guide. The kymograph of course was adjusted so that the stylus would scratch lightly upon the smoked paper. Plate 6, page 57 shows the kymograph in position and some of the records traced upon the drum.

Web straps, 3/4ths inches wide, were fastened on the base board in front of the finger-piece so that the subject's index finger, third, and little finger, hand, wrist, and forearm could be strapped down leaving only the middle finger free to flex against the spring after it was harnessed in the finger-piece. Felt padding attached to the base board protected the subject's knuckles from rubbing against the wood in the strapped areas. This, in simple detail, constituted the ergograph. An account of its operation will be left for the next section treating the method of collecting data.

3. METHOD OF COLLECTING DATA

When the subject came in according to his schedule to take his daily record, he was first required to write a brief daily report, a sample of which appears on the next page. The information required is almost self-explanatory. Since many of the subjects came in for their testing during the early morning period, the inquiry as to type of night life was included. Some typical answers to this question include: Late card party; Attended exciting basket-ball game; Late study for exam; Movies; Concert; Fraternity roughhouse; and Bull-festing. The majority report "Quiet evening and study". Almost any sort of answer can be expected to the question "What have you been doing just previous to taking this record?" In order to get some sort of an introspective estimate of the subject's strength and well-being he was asked to rate himself on a scale of 1 to 10 to indicate how strong he felt just previous to taking the record. Ten was to indicate a feeling of maximum strength, the best he

DAILY REPORT BLANK

Subject:

Time of day: Date:

What have you been doing just previous to taking this record?

Estimate of hours of sleep the night before:

Type of night life (study, late party, quiet evening, etc.):

How strong do you feel at the present moment?

1 2 3 4 5 6 7 8 9 10

Last meal:

had ever felt; one, of course, was an estimate of extreme weakness; and five, average strength. In addition he was asked to write any qualifying remarks if he felt they were necessary. The subject's estimate in many cases varied from day to day. Some subjects, however, fell into a rut of checking the same figure each day, although they were warned at various intervals to be sure to check as they actually felt. Several students reported weakness because of head colds, extreme physical exercise, or even sick stomach just previous to taking the record. All these points will be considered in the discussion of the individual records. A statement regarding the time of the last meal (even a candy-bar) was requested, because a special study of the effect of eating just previous to record taking was desired.

The literature abounds with reports upon the various effects of external influences upon strength of grip, or the work curve in ergography. Several of these studies may be thrown out of court at once as careless in plan and merely illustrative of the early blind infatuation for the ergograph. But a few of the early studies in this connection are worth noting at this point. In regard to stomach contractions and strength of grip, Tomi Wada (67) reports an interesting experimental set-up. Her subjects swallowed a deflated balloon and tube, the outer end of which was attached to a recording device. The balloon was inflated, and any contraction in the stomach would be transmitted to a writing lever and result in a rise in a curve traced on a kymograph. The operator watched the record, and when a period of either quiescence or contraction was firmly established, she signalled the subject to exert his maximum grip in the dynamometer. Subjects pulled from six to twelve kilograms better with an empty stomach than with a full one.

Whipple (76) summarizes several German and French reports relative to external influences affecting ergography and dynamometer recordings. Since Whipple makes reference to the original investigations, the results alone are stated here, and the single reference to Whipple above is sufficient. The effect of physical work upon the ergographic curves seems to vary with the physical condition of the individual and with the nature and duration of exercise. Thus Bolton (76) found his ergograms decreased by a 2-hour walk. Kraeplin (76) on the other hand found a 1-hour walk caused at first a transient improvement and then a reduction in his ergograms. Smedley (56) tested Chicago school children with a dynamometer before and after a 40-minute class exercise in the gymnasium, with the results that the stronger pupils were little affected whereas weak and nervous pupils were decidedly exhausted.

Extensive study of the effect of mental work on physical endurance has yielded discordant results. Bolton (76) reports that two hours of adding definitely increase the ergograph record. Larguier (76) supports this contention. Clavière (76) on the other hand, reports that two hours of intense mental work produces a definite and proportionate diminution of muscular force, whereas intellectual work of medium intensity does not produce any appreciable weakening of endurance. In an extensively quoted study, Kemsies (76) reports: (a) that the ergograph is a reliable indicator of true fatigue, (b) that the subjective report of bodily feeling may not accord with real capacity, and (c) that various German school subjects can be arranged in rank from highest to lowest in their effect upon shortening the endurance curve, gymnastics ranking first and drawing last. Binet and Henri (76) make the distinction between mental work conducted without emotion and that conducted with emotion, the latter producing a transient increase followed by a rapid decrease in endurance. Kraeplin (76) somewhat similarly concludes that while hard mental work certainly reduces muscular energy, deviating results may appear in ergograms on account of the condition of excitement (Aufregung) that normally accompanies all mental work, and that may be expected to affect, either positively or negatively, the tracings on the ergograph which follow such work.

Smedley and Christopher (56) at Chicago indicate a thorough-going positive correlation between endurances as measured by the dynamometer and class standing. Again boys in the school for the incorrigible, and truant children, were found to exhibit at every age less endurance (62-82%) than normal boys of the same age according to the Chicago report. Likewise, the endurance of boys was greater than that of girls at all ages.

According to Lombard (39), endurance on the ergograph is increased by sleep, food, exercise, increased atmospheric pressure and small doses of alcohol, but lessened by general and local fatigue, hunger, decreased atmospheric pressure, high temperature, high humidity, and tobacco. Kraeplin (76) finds that small doses of alcohol, 15 to 20 grams, at first cause a considerable increase in the ergograms - but the effect soon disappears. Rivers and Webber (76), however, find that small doses of alcohol produce no effect whatever if the subject is kept in ignorance as to when the alcohol is administered. Harley (25) seems to find that smoking has little influence on the shape of ergograms.

This short reversion to the literature will indicate the reason for requesting the daily reports in the present study. An effort was made thereby to keep a check on some of the most likely causes for individual variation, as well as the daily variation of each subject's own curve.

When the subject had filed his report, in the first study, he was given the hand dynamometer with its face smoked, and thehandle set for his own particular hand. The best grip-set of the handle had been determined imperically during the practice period for each subject. A record of the grip-set of the handle for each subject was kept constantly at hand so that conditions were held rigidly constant for this likely variable. The subject was instructed to hold the dynamometer in the preferred hand, letting it hang loosely by his side. (See Plate #7, page 65.) The metronome, set at 120 so that it would beat once every half second, was started. When the subject thought that he had caught the "feel" of the rhythm, he signalled the operator who lifted the catch controlling the clock mechanism, and the subject gripped repeatedly once every half second in time with the metronome until he was exhausted. No single trial lasted a full two minutes, and only those with the greatest endurance went to a minute and a half. Each day

P L A T E 7

Subject Gripping Dynamometer in Time with Metronome.

the instructions were simple and the same. "Grip your maximum each time, keep in time with the metronome and grip until you are entirely exhausted".

The problem of rhythm is important and it was the one item which was stressed the most during the practice periods. Most subjects caught the rhythm rather easily, but one or two subjects had difficulty at first. One subject in particular had difficulty in keeping the rhythm and relaxing between each grip. If he relaxed he lost rhythm, and if he kept in time, his "holding" was abnormally high. Even during the study period it was necessary to coach him in this respect. Finally, toward the end of the period, he had mastered both the rhythm and the holding problem. Some of the subjects had difficulty once in a while in keeping rhythm toward the end of the recording when they were most fatigued. They complained that their muscles, especially those of the forearm, were tightening up and they could not grip any faster. However, with an effort even this was overcome.

When the subject had finished, the smoked paper bearing his work curve was unfastened from the face of the instrument. By means of a wire stylus, his name, the date, and the time of recording were scratched in the smoked paper next to his work curve. The paper was then run through the alcohol-shellac bath and hung up to dry next to the steam radiators in the laboratory. A record would dry in this manner within five minutes, and be ready for handling with no danger of its being wiped out. All the original records thus permanently preserved which are not included herein are on file at the Psychology Department of the Massachusetts State College.

In the second study, conditions were exactly the same except that the ergograph was used, and only thirteen of the same twenty-two subjects participated. The subject was seated at the table to which the instrument was fastened and was required to place his forearm through the straps, palm of the hand uppermost. His middle finger was fitted into the finger-piece, so that the maximum pull would come just below the first joint. His arm was then moved back so that he would just take up the slack of the pulling loop to which the finger-piece was fastened. Straps were then tightened so that he was held securely at the forearm, the wrist, and across the upper part of the hand. In addition, the index finger and the third and fourth fingers were also securely strapped. The subject was instructed daily to flex his middle finger in time with the metronome, to pull his maximum at each beat, and to flex his finger until he could flex it no longer. These instructions were constantly in front of him on a large sheet of white cardboard which concealed his record as it was being traced on the kymograph. (See Plate 8, page 68.) During the two weeks practice period, it had been found that the curves were longer and higher when the majority of the subjects viewed their own record as it registered than when it was hidden from view. In order to keep conditions constant for all, the blind was used throughout the study. In the first study with the dynamometer, this factor of competing against self did not enter in. The subjects were preoccupied watching the metronome, and found it awkward to glance down as they gripped. On one or two occasions

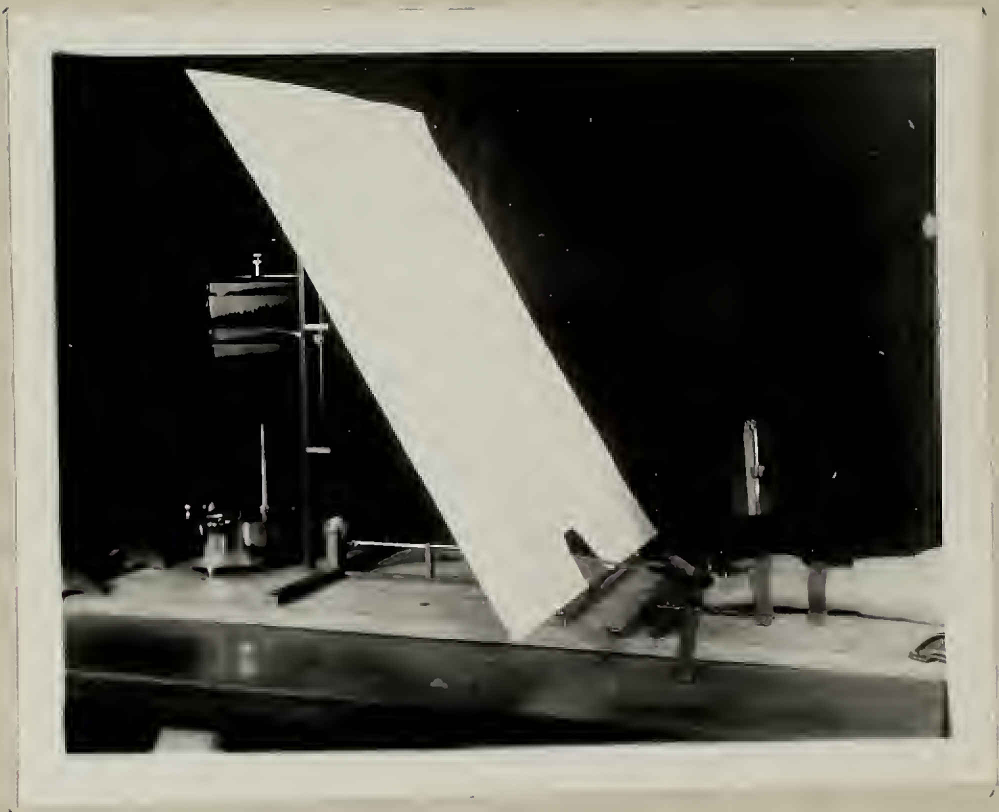


PLATE 8

Subject Strapped in Ergograph.

when this was attempted they were warned against it.

As with the dynamometer, the entire work period per subject did not last much over a minute and a half. More than one subject's curve could be placed on the kymograph, so that it was not necessary to change and smoke paper between each recording as was the case in the dynamometer study. Anywhere from six to nine curves were sometimes recorded on one sheet of smoked paper. The records were preserved in the usual manner by running them through the alcohol-shellac bath.

In this study, the subjects were not bothered much in catching the rhythm wich was still set at one beat every half second. Probably this was due to the previous training in the first study, Nor was there as much "holding" in the ergograms as there was in the dynamometer recordings. In fact, only three people evidenced enough holding to make a special study of this effect worth while. All the other subjects relaxed completely between pulls so that each tracing went back to the base line each time. This complete relaxation on the part of the majority of the subjects did not hold true early in the practice period, however. During the early trials every one exhibited holding effects just as they had done with the dynamometer. However, in this second study they were continually reminded to relax between grips, and by the time the practice period was over, all but three had learned to relax completely. These three, however, kept on holding even through the study period. One of the three occasionally produced a curve showing little or no holding, but more often holding was definitely present. Another reason that may account for the more general and complete relaxation in this study is the possibility that with a smaller group of muscles involved, even pulling once every half second afforded too much chance for natural recuperation between pulls. There was perhaps a smaller area fatigued than would be affected by work on the dynamometer, and c consequently there was a greater chance for circulation of the blood and lymph so that fatigue products could be taken away readily.

4. SUBJECTS

Of the twenty-two subjects participating in the first half of the experiment, there were eight women, thirteen men, and one boy. The ages of the subjects ranged from 10 to 50 years, but the majority fell in a range of from 19 to 23 years. Most of the subjects were college students or people connected with the college. Two professors, two graduate students, 3 coll-seniors, 6 juniors, 2 sophomores, 2 freshmen, and one school boy, 5th grade, participated. The remaining four subjects were women employed doing clerical and statistical work in various departments of the college. All four of these women were college graduates, and two were housewives besides. Physical strength of the group ran the gamut from the weak and flabby to the strong and physically active among both men and women.

Of the children available for testings, only one was able to keep the rhythm with any degree of accuracy, and he, as chance would have it, was left-handed. Only one other subject, a woman, expressed a preference for the left hand. The boy's record on the dynamometer was erratic and non-reliable in spite of the fact that he seemed to keep the rhythm. Unfortunately his school hours conflicted with his laboratory dates, and he was unable to participate in the work on the ergograph. The study then can throw little light upon the work of children under these conditions. It is interesting to note that Bolton and Miller (76) report that ergography is not adapted for measuring fatigue among school children because of their susceptibility to pain and, oftentimes, incomplete coordinations. Certainly the gripping coordination of the boy was not as smooth as could be desired although he was a willing and eager subject.

One subject afforded an interesting case study relative to the effect of the age factor upon fatigue curves. This subject, Dr. Glick himself, was able to produce his own work curves taken in his early study in 1914, for a comparison with his present curves. Special note of this will be made later.

During the recruiting of the subjects, they were asked to fill out an information blank, a sample copy of which appears on page 72. From this blank detailed information about each subject was obtained. Short case histories of each subject based on this data appear below.

A Roman numeral takes the place of the subject's name. This numeral will be used to designate the subject henceforth. An asterisk before the subject's number will mean that he took part in both studies.

Of the thirteen participating in the second study, utilizing the ergograph, six were women and seven were men. All thirteen had taken part in the first study also.

*<u>Subject I</u>. Young woman. Age 23. Height 5 ft. 9 in. Weight 160 lbs. College graduate. Housewife and statistician.

# INFORMATION BLANK

Subject: Height:

Age: Weight:

Usual type of occupation:

Estimate of scholastic achievement:

(a) Average school grade:

(b) Mental test ratings (if any):

Account of athletic record:

What sports, if any, are you engaged in now?

How much time daily do you put into athletics?

Any other hard physical exercise:

Type of high school:

Previous work:

Grip set at: _____

High scholastic standing. Only type of physical exercise is occasional bicycling, about half hour per day. Active in college athletics. Small town background. Has been waitress, governess, and done clerical work.

*Subject II. Young man. Age 24. Height 5 ft. 6 in. Weight 148 lbs. Graduate student in psychology. Very high scholastic standing. Not much physical exercise at present except occasional outdoor camping and cycling. Active formerly in basketball, soccer, and track. City life. Worked since high school in factories, garage, and camps.

Subject III. Young man. Age 21. Height 5 ft. 11¾ in. Weight 140 lbs. College senior. Student janitor. Fair scholastic standing. Active in soccer, basketball, and track until a year ago. Physical workout - wrestling and boxing twice a week at present. Country life. Farmed every summer except last three years. Clerked in a store.

Subject IV. Young man. Age 20. Height 6 ft. 2 in. Weight 195 lbs. College junior. Good scholastic standing. Very active in baseball, soccer, football and basketball. Varsity basketball at present, 2 hours practice daily and games. Country life. Farming and truck driving.

Subject V. Young woman. Age 22. Height 5 ft. 4 in. Weight 122 lbs. College graduate. Clerical work. Very high scholastic standing. Fairly active in athletics formerly. No physical exercise at present. Country life. Farmerette.

*Subject VI. Young man. Age 19. Height 5 ft. 8½ in. Weight 145 lbs. College junior. Laboratory assistant in psychology. High scholastic standing. Active in high school crew.

No physical exercise at present. City life. Factory work.

*Subject VII. Young man. Age 22. Height 5 ft. 4 in. Weight 145 lbs. Graduate student in psychology. Good scholastic standing. Active in college football and baseball but no physical exercise at present. Comes from a semi-rural background. Previous work in camp counseloring.

Subject VIII. Young woman. Age 28. Height 5 ft. 6½ in. Weight 125 lbs. College graduate, Master's degree. Statistician. Very high scholastic standing. Never much physical exercise and hardly any for past six years. City life. No other work except college training and present job.

Subject IX. Young man. Age 19. Height 5 ft. 11½ in. Weight 170 lbs. College sophomore. Good scholastic standing. Very active in high school and academy athletics. Not much physical exercise at present. Active in college debating. Small town background. Clerk in store. Mostly farming since a boy.

*Subject X. Man. Age 52. Height 6 ft. Weight 195 lbs. Professor of psychology. Considerable physical exercise, farming. Once very active in college baseball. Farm work since a boy. Grade and high school teaching in past as well as collegiate.

*Subject XI. Young man. Age 20. Height 5 ft. 9 in. Weight 145 lbs. College sophomore. Good scholastic standing. Active in hockey, tennis and soccer. At present time on varsity hockey squad, one hour practice daily. Small town life. Worked as office boy and cotton mill hand.

*Subject XII. Young woman. Age 19. Height 5 ft. 4½ in. Weight 128 lbs. College junior. Poor scholastic standing. Fairly active in tennis, swimming, and bowling. At present bowls three or four strings a week. Small town life. Has been waitress and done housework.

Subject XIII. Young man. Age 23. Height 5 ft. 6 in. Weight 140 lbs. College senior. Fair scholastic standing. Active in track - dashes. Puts in ½ hour practice daily. Small town life. Worked as florist.

*Subject XIV. Young man. Age 17. Height 6 ft. Weight 155 lbs. College freshman. Good scholastic standing. Basketball, tennis, and swimming in high school. Puts in 4 hours per week in swimming and basketball at present. Small town life. Factory worker.

*Subject XV. Young woman. Age 21. Height 5 ft. 4 in. Weight 135 lbs. College junior. Good scholastic average. No time for athletics. Hard worker - cooking and house work to earn board and room. Walks from 2 to 8 miles daily. Country life. Farmerette.

*Subject XVI. Young woman. Age 20. Height 5 ft. 2 in. Weight 112 lbs. College junior. Fair scholastic standing. Some athletics in college, not much at present except occasional riding. City high school. Waitress.

*Subject XVII. Young woman. Age 27. Height 5 ft. 2 in. Weight 110 lbs. College graduate. Good college record. Statistician and housewife. No hard physical work for last 7 years. City life. Private school and large university. Various important office positions.

*Subject XVIII. Man. Age 32. Height 6 ft. Weight 198 lbs. Assistant professor of psychology. Likes tennis and swimming. No hard physical work at present. City life. Teaching and clinical work.

Subject XIX. Young man. Age 20. Height 5 ft. 5 in. Weight 112 lbs. College junior. Fair scholastic standing. Active in track and cross country. Captain of cross country. Never walks - always running or cycling. Very energetic and active on various editiorial and business boards. City life. Newspaper mailing office.

Subject XX. Young man. Age 20. Height 6 ft. 3 in. Weight 187 lbs. College freshman. Poor scholastic standing. Very active in athletics during high school. Out for basketball and spring football at present - 4 hours per week. City life. Sings with orchestra. Runs delivery truck, and has done considerable tree surgery.

Subject XXI. Boy. Age 10. Height 4 ft. 8 in. Weight 78 lbs. Grade 5. Very good student. Quite nervous and full of questions. Does not stay put a minute. Fairly active in boys' games - basketball and skating are the games of the hour. Small town life. Few chores to speak of.

*Subject XXII. Young woman. Age 21. Height 5 ft. 7 in. Weight 120 lbs. College senior. Fair scholastic standing. Swimming and hiking have been pretty constant activities. Not much of this at present, but some swimming. City life. Store clerking.

5. METHOD OF TREATING DATA

As has been said, when the records from the dynamometer were read, the readings could be translated directly into kilograms gripped, or, in the case of "holdings", kilograms held. It was found convenient to represent these readings on ordinary cross section paper in order that the nature of the curve could be seen at a glance. The number of individual grips per subject however sometimes greatly exceeded the number of blocks on the cross-section paper. Very often there were about twice as many individual grips recorded than could be plotted conveniently upon the paper. Inorder to represent every curve so that comparisons could be made, the following method was employed. Every two successive readings on each individual record were averaged, and it was this averaged series of readings that was plotted on the cross-section paper. The effect of such averaging simply shortened the length of the curve one half, and smoothed the curve slightly. Otherwise no change in the shape of the curves resulted because of this averaging. In fact, it was much easier to compare the treated data, than it was the longer more irregular curves plotted from the raw data. The folding of long sheets of graph paper would have made the volume a decidedly bulky job. Because the number of curves required for four similar volumes was so large, only one set of curves were drawn in order that duplicates could be blue-printed. It is the blue-printed duplicates that appear herein. The original drawings are filed with the Department of Psychology at the Massachusetts State College.

In the graphs thus drawn representing the various work (or fatigue) curves, there was a fixed abscissa on which every unit of horizontal space represented one second of work. The ordinate of each graph represented a variable scale in order that as many curves could be placed on one page as space would allow. The grouping of several curves on one page facilitated ready comparisons. What was done was to begin the first curve on each page as close to the top of the graph paper as was possible, selecting for the curve an arbitrary and convenient zero point. The height of the initial contraction in kilograms as well as the height of the final contraction in kilograms, marked the beginning and end points of the curve. Each unit of vertical space represented one kilogram of force exerted, so that each of the ordinates represented the amount gripped in kilograms at each second of work. Now in order to get several curves on one page, the initial points of these curves were dropped five or ten (more frequently the latter ) units of vertical space from the initial point of the curve above, and the curves were plotted from there. This arbitrary lowering was necessary, of course, in order that the curves would not cross. Lowering the initial points, of course, had the same effect as lowering the zero point of each curve on the page five, ten, twenty, or thirty units, as the case may be, below the original zero point of the first curve plotted at the top of the page. In each instance, the figure expressing the initial and final contraction in kilograms gripped was written at the beginning and end of each work curve.

The individual curves of a single subject very often required more than a single page in order to be represented. When several pages were required for a single subject, those curves appearing on any one page were grouped in sets according to the time of recording. Even when all the curves fitted on one sheet, the morning curves were grouped first, then the curves taken after eating, and finally, the afternoon curves. The data as to time of recording was recorded in upper right hand corner of the page under the title of each graph. In the left hand margin, the number of each individual curve was recorded beside the initial grip of that curve.

In plotting the curves for work on the ergograph, the same method of treating the data was employed. However, the units represented by the ordinates were not expressed in kilograms pulled but rather in millimeters thrown. That is, the height of each contraction as it registered on the kymograph was measured by a millimeter rule, and it is the averaged value of each succeeding two pulls as thus measured which was recorded on the cross-section paper. Thus each ordinate represented the height of each contraction as measured in millimeters during each second of work. The spring against which the subject pulled was calibrated so that a pull of one kilogram yielded a 11.5 mm. throw. Table I showing the equivalent kilogram values for millimeters of measurement will be found on page 80. The spring was tested at various intervals, and the values remained relatively the same. It is interesting to note with what regularity the scale ascends. As nearly as could be determined, Table I represents the actual relationship between the force exerted and height of contraction in any single pull. When the height of throw was less than 2 mm., the amount of force exerted was almost negligible. It is interesting to note that the majority of subjects exerted about 13 times as much force per contraction on the dynamometer than they did on the ergograph. For example, a glance at the average work

TABLE 1.

Relation of Millimeters Thrown to Kilograms Pulled on Ergograph.

| Millimeters | Kilograms |
|---|---|
| 2.0 | .05 |
| 2.5 | .10 |
| 3.0 | .15 |
| 3.5 | .20 |
| 4.0 | .25 |
| 4.5 | .30 |
| 5.0 | .35 |
| 5.5 | .40 |
| 6.0 | .45 |
| 6.5 | .50 |
| 7.0 | .55 |
| 7.5 | .60 |
| 8.0 | .65 |
| 8.5 | .70 |
| 9.0 | .75 |
| 9.5 | .80 |
| 10.0 | .85 |
| 10.5 | .90 |
| 11.0 | .95 |
| 11.5 | 1.00 |
| 12.0 | 1.05 |
| 12.5 | 1.10 |
| 13.0 | 1.15 |
| 13.5 | 1.20 |
| 14.0 | 1.25 |
| 14.5 | 1.30 |
| 15.0 | 1.35 |
| 15.5 | 1.40 |
| 16.0 | 1.45 |
| 16.5 | 1.50 |
| 17.0 | 1.55 |
| 17.5 | 1.60 |
| 18.0 | 1.65 |
| 18.5 | 1.70 |
| 19.0 | 1.75 |
| 19.5 | 1.80 |
| 20.0 | 1.85 |
| 20.5 | 1.90 |
| 21.0 | 1.95 |
| 21.5 | 2.00 |
| 22.0 | 2.05 |
| 22.5 | 2.10 |
| 23.0 | 2.15 |
| 23.5 | 2.20 |

| Millimeters | Kilograms |
|---|---|
| 24.0 | 2.25 |
| 24.5 | 2.30 |
| 25.0 | 2.35 |
| 25.5 | 2.40 |
| 26.0 | 2.45 |
| 26.5 | 2.50 |
| 27.0 | 2.55 |
| 27.5 | 2.60 |
| 28.0 | 2.65 |
| 28.5 | 2.70 |
| 29.0 | 2.75 |
| 29.5 | 2.80 |
| 30.0 | 2.85 |
| 30.5 | 2.90 |
| 31.0 | 2.95 |
| 31.5 | 3.00 |
| 32.0 | 3.05 |
| 32.5 | 3.10 |
| 33.0 | 3.15 |
| 33.5 | 3.20 |
| 34.0 | 3.25 |
| 34.5 | 3.30 |
| 35.0 | 3.35 |
| 35.5 | 3.40 |
| 36.0 | 3.45 |
| 36.5 | 3.50 |
| 37.0 | 3.55 |
| 37.5 | 3.60 |
| 38.0 | 3.65 |
| 38.5 | 3.70 |
| 39.0 | 3.75 |
| 39.5 | 3.80 |
| 40.0 | 3.85 |
| 41.0 | 3.95 |
| 42.0 | 4.05 |
| 43.0 | 4.15 |
| 44.0 | 4.25 |
| 45.0 | 4.35 |
| 46.0 | 4.45 |
| 47.0 | 4.55 |
| 48.0 | 4.65 |
| 49.0 | 4.75 |
| 50.0 | 4.85 |

curves of Subject VI on the dynamometer and ergograph ( Fig. 13 , page ) will indicate where he gripped about 34 kilograms on the dynamometer for an average initial contraction. On the ergograph, he exerted a pull of about 3.4 kilograms (or a 35.2 mm. throw). This can be checked by Table I. This does not mean that a 10 to 1 relationship always held. In some cases the ergograph record was much lower, making the relationship nearly 15 to 1. The average ratio was about 13 to 1, however.

A set of individual curves illustrating each subject's daily work on the dynamometer was plotted. The number of curves per subject varied from five to ten depending on the number of times the subject could keep his appointments. The majority of subjects, presented at least seven to eight daily curves. Likewise a set of individual curves for the thirteen working on the ergograph was plotted. Again most people completed about eight curves. For the twenty-two subjects on the dynamometer, individual daily holding curves were also drawn. There were only three subjects in the second study who exhibited persistent holding (Subjects II, X, and XI). Their daily holding curves were likewise plotted.

Next, for each of the nine subjects who participated only in the dynamometer study, an average work curve and an average holding curve was computed from each individual's daily records. These average curves were plotted on a separate sheet for each individual. For each of the thirteen subjects who took part in both studies, average work curves for both ergograph and dynamometer were drawn. On the same sheet with these averaged curves were drawn the averaged dynamometer holdings for each of the thirteen subjects, and the averaged ergograph holding curve in the case of the special 3.

In addition, five special group curves were drawn. One represented the average work curve of the entire 22 subjects on the dynamometer. The second represented the average work curve on the dynamometer of the thirteen subjects who participated in both studies. The third represented the average work curve on the ergograph by the same thirteen. The fourth represented the average holding curve on the ergograph by the special three. And the fifth represented the average holding curve of these same three on the dynamometer. The holdings of the entire 22 subjects on the dynamometer were so extreme in certain cases that an average curve for the group would probably not mean much, so this curve was not drawn.

A special study was conducted with Subject X in order to indicate, at least in part, the effect of age and time upon the work curve of the dynamometer. Curves which he had produced on a similar instrument in 1914 were treated the same as the present data. That is, the force of every two successive grips was averaged, and the fore-shortened curves were drawn. Then the average of these individual curves was compared with his average curve in the present study.

The record sheets containing the original readings from both the dynamometer and the ergograph, the all too lengthy tables containing the figures for individual average curves as well as group average curves, and all the original records from each apparatus could hardly be placed in this volume for all to see. All this data has been placed on the graphs and must be obtained from them. Should any one question the results, all the original material along with the daily report blanks of each subject is filed at the Psychology Department of the Massachusetts State College, and may be seen upon request.

It is almost necessary, however, to look upon work curves of this study as individual affairs. Hardly any two curves of even the same subject were of exactly the same duration each day. Among the individual curves of any one subject there was, however, very little deviation in length from day to day. A few individuals gave one or two abnormally short or abnormally long curves, but most people kept the length of their own curves within reasonable limits. But when one attempts to compare one subject with another, it is impossible to do it point for point. Some subjects will run almost twice as long as others. This fact alone renders any statistical treatment of the data in terms of averages almost useless. It would not be fair to cut all the curves back to the shortest, nor to take the average length curve as the maximum length and neglect any points in other curves that go beyond the final contraction of this average length curve. If an arbitrary number of contractions had been chosen, say sixty or seventy grips on the dynamometer and forty to fifty pulls on the ergograph, for each subject to strive to complete each day, it would have made a statistical interpretation possible, but a true picture of fatigue would not have been obtained in each case. All these facts indicate that extreme caution must be employed in interpreting the group curves resulting from this study.

Since the present data would not lend itself readily to statistical manipulation, the source of group tendencies had to be derived by some other means. A cursory glance at the data indicated that vast differences in performance existed between individuals. Each individual, however, produced daily results that were quite similar. Where variations occur they occur for some definite reason. An analysis resulted in the following possible causes of variation: time of day, type of work - mental or physical - and any specific activity under each of these headings, eating previous to record taking, amount of sleep, presence of audience, subject's own estimate of physical well-being before taking record, and emotional disturbances. In order to find the general effect of each of these variables upon work done on the dynamometer, a summary had to be made of each individual's work curves in relation to his daily reports. These summaries were derived by constructing a sort of exhaustive classification key for each subject by which each of his curves could be classified and compared with references to the causes of variation listed above. These keys will be found in the appendix, pages 261 to 300.

A grand resume of these individual summaries constituted the data relative to group tendencies on the dynamometer. The work on the ergograph had to be treated similarly. Using these keys as guides, an analysis of the holdings was made in both studies. No special keys for holding were drawn up, however. Finally an analysis was made of each individual's average curve in each study in order to discuss the fluctuations in the general average curve for work on both dynamometer and ergograph, so that a comparison of the two studies could be made.

## 6. PRESENTATION, DISCUSSION, AND INTERPRETATION OF DATA

In this section, the following scheme of organization is employed:

A. Dynamometer Study.

- I. Individual Work Curves and Holding Curves.
- II. General Discussion and Resume of Individual Summaries Relative to Group Tendencies.
- III. General Discussion and Interpretation of Holdings.

B. Ergograph Study.

- I. Individual Work Curves.
- II. General Discussion and Resume of Individual Summaries Relative to Group Tendencies.
- III. Holding Curves and Their Discussion.

C. Group Summaries.

- I. Individual Average Curves.
- II. Group Curves on Dynamometer and Ergograph
- III. Analysis of Group Curves.

D. Summary of Conclusions

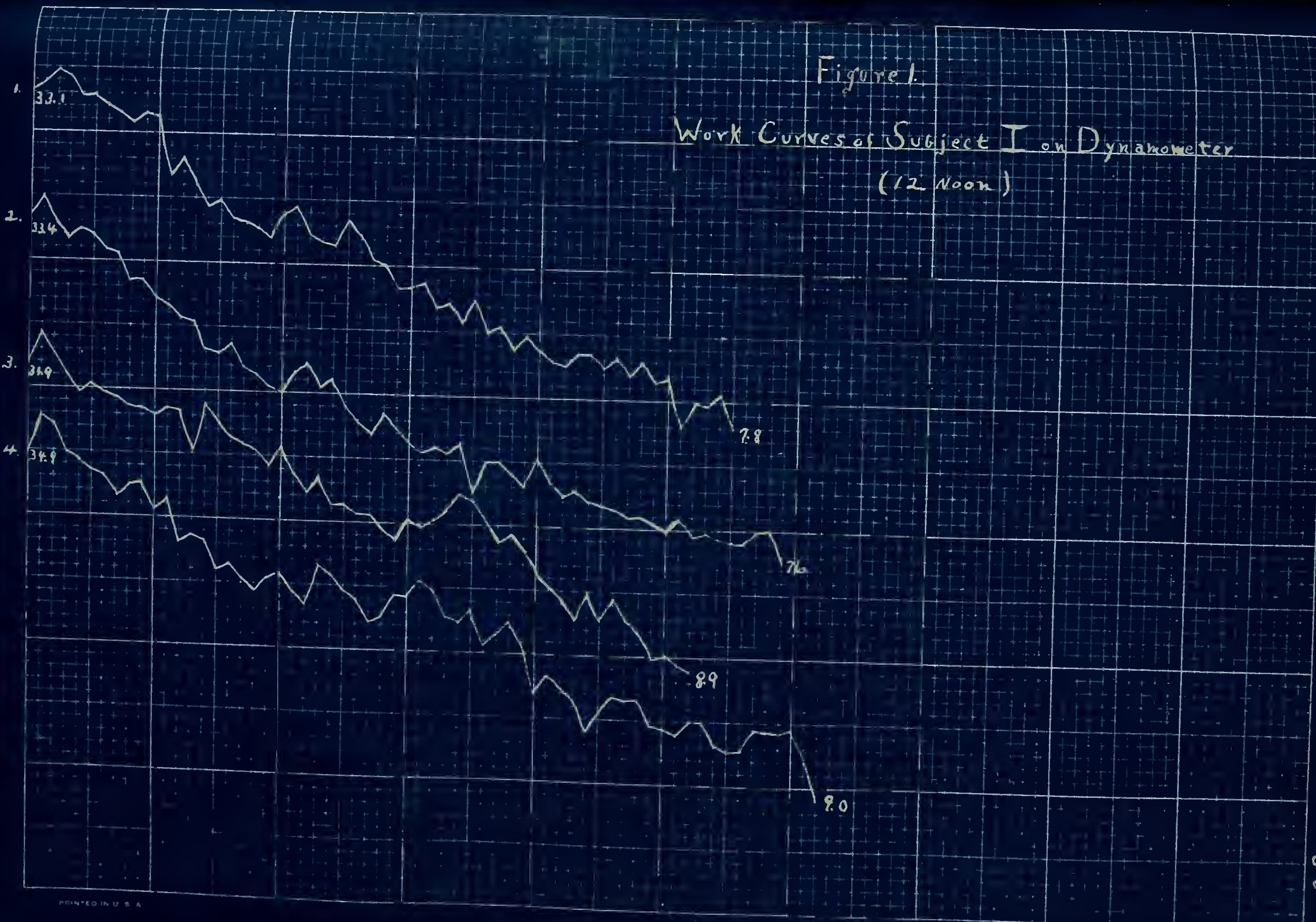



Figure 1.

Work Curves of Subject I on Dynamometer

(12 Noon)

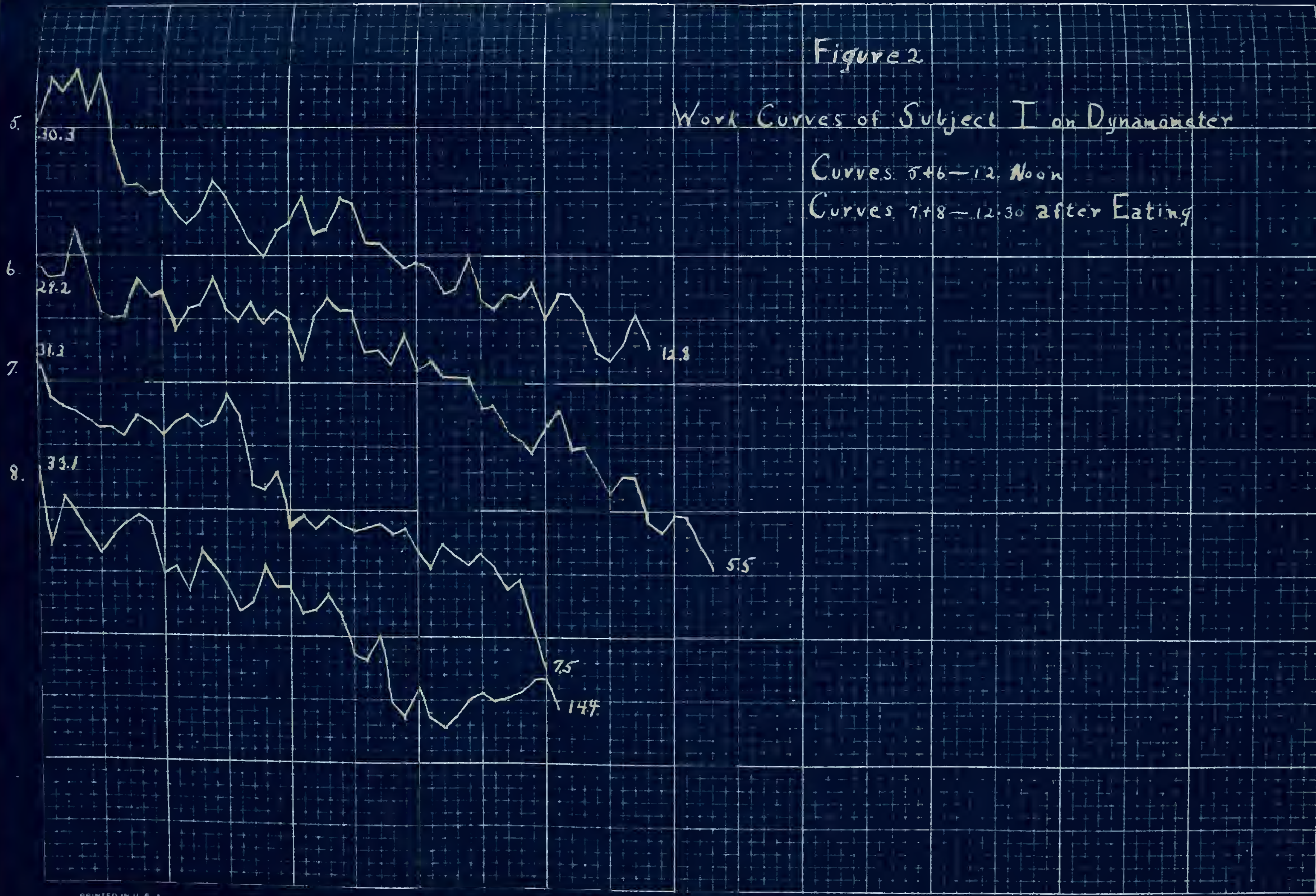



Figure 2

Work Curves of Subject I on Dynamometer

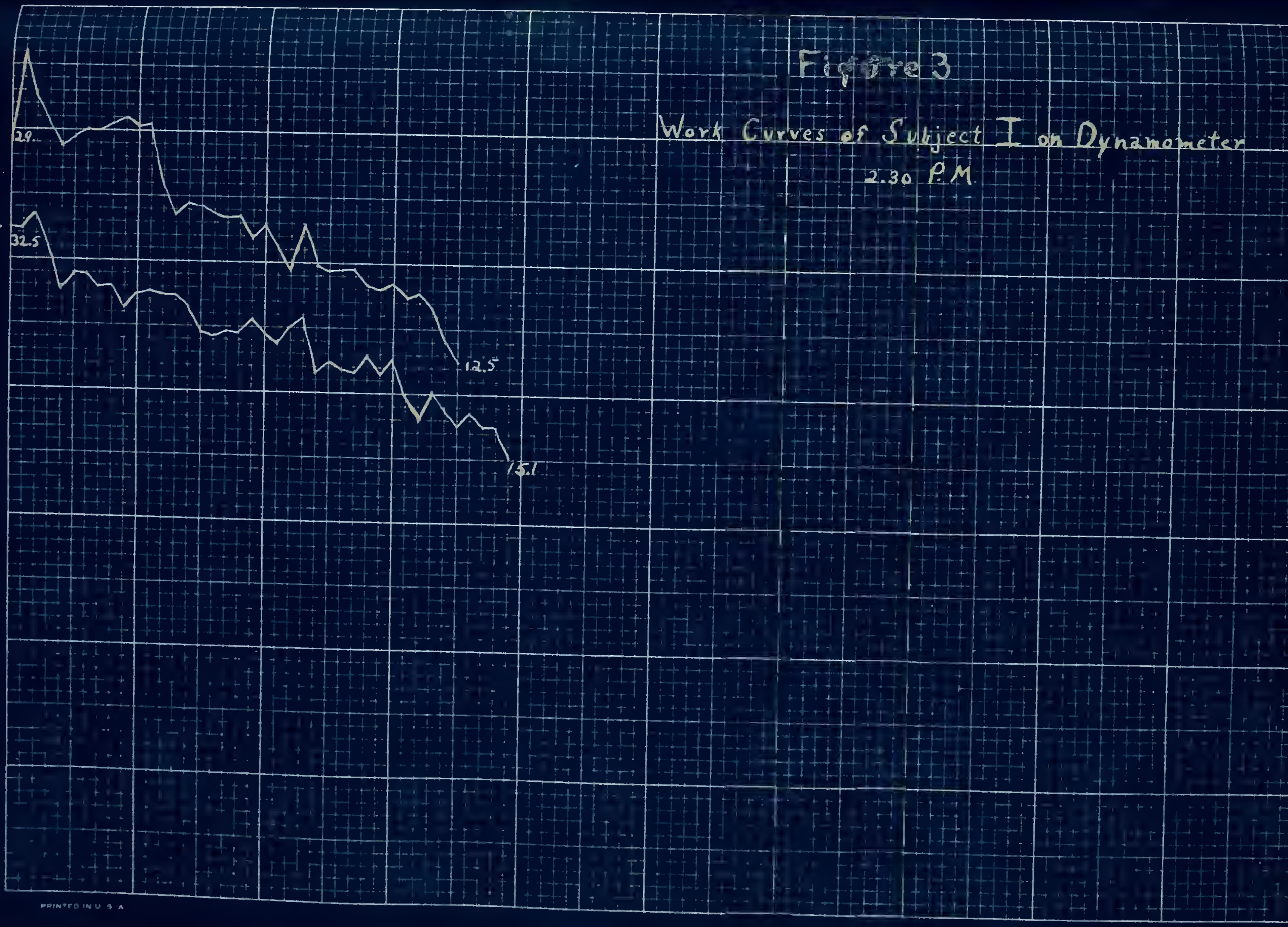



Figure 3

Work Curves of Subject I on Dynamometer

2.30 P.M.

Figure 4

Holding Curves of Subject I on Dynamometer

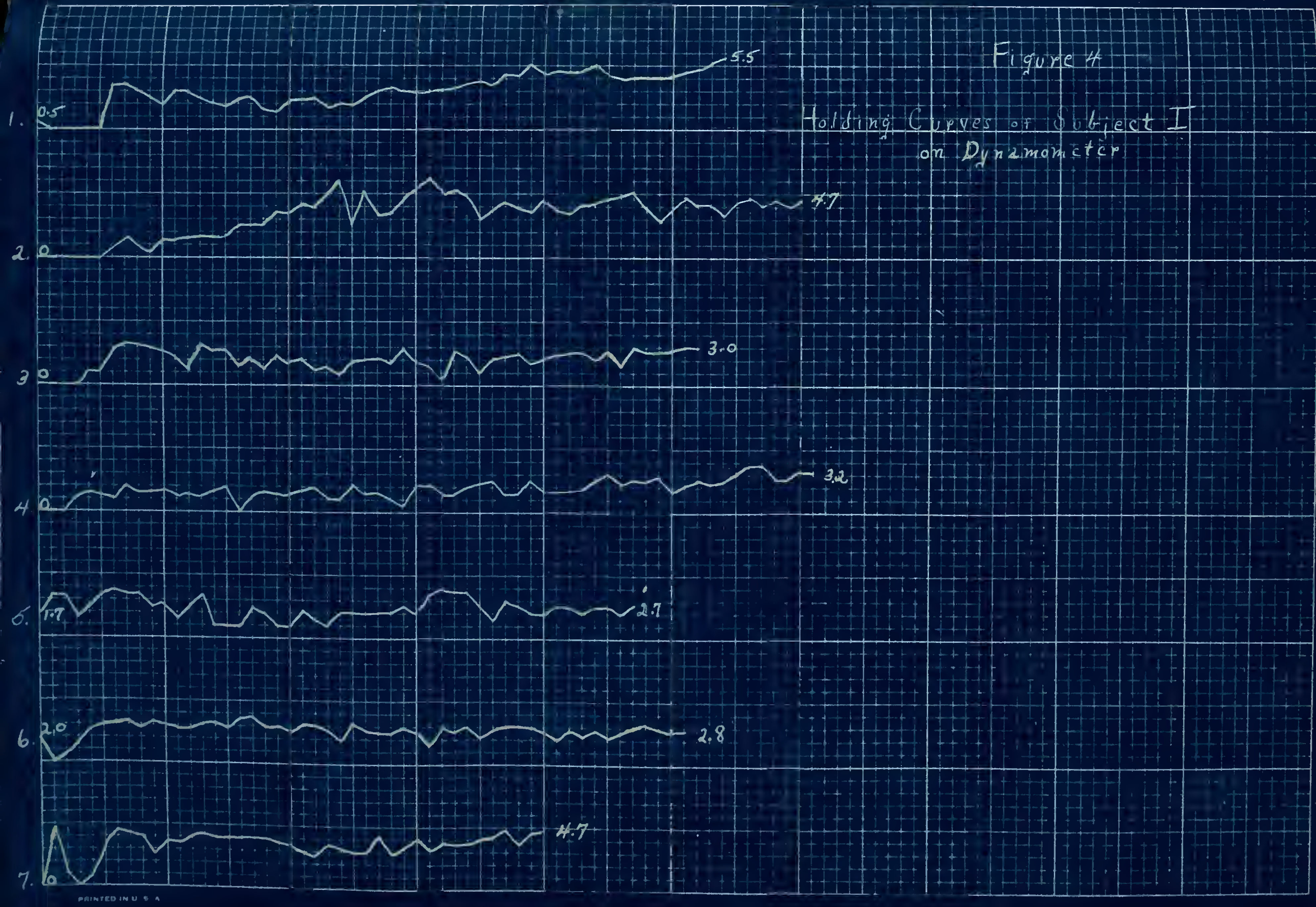



Figure 5

Holding Curves of Subject I on Dynamometer

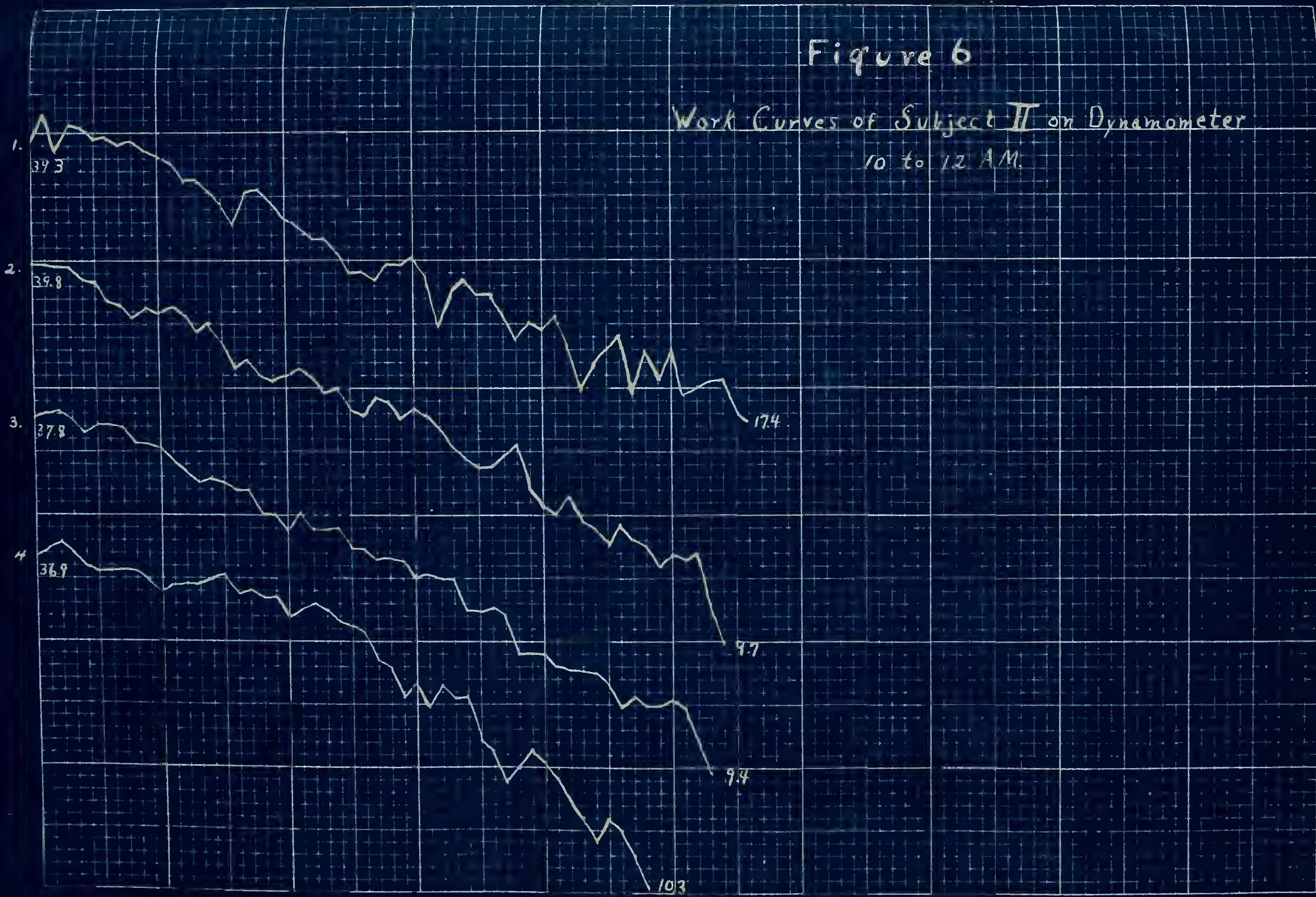



Figure 6

Work Curves of Subject II on Dynamometer
10 to 12 A.M.

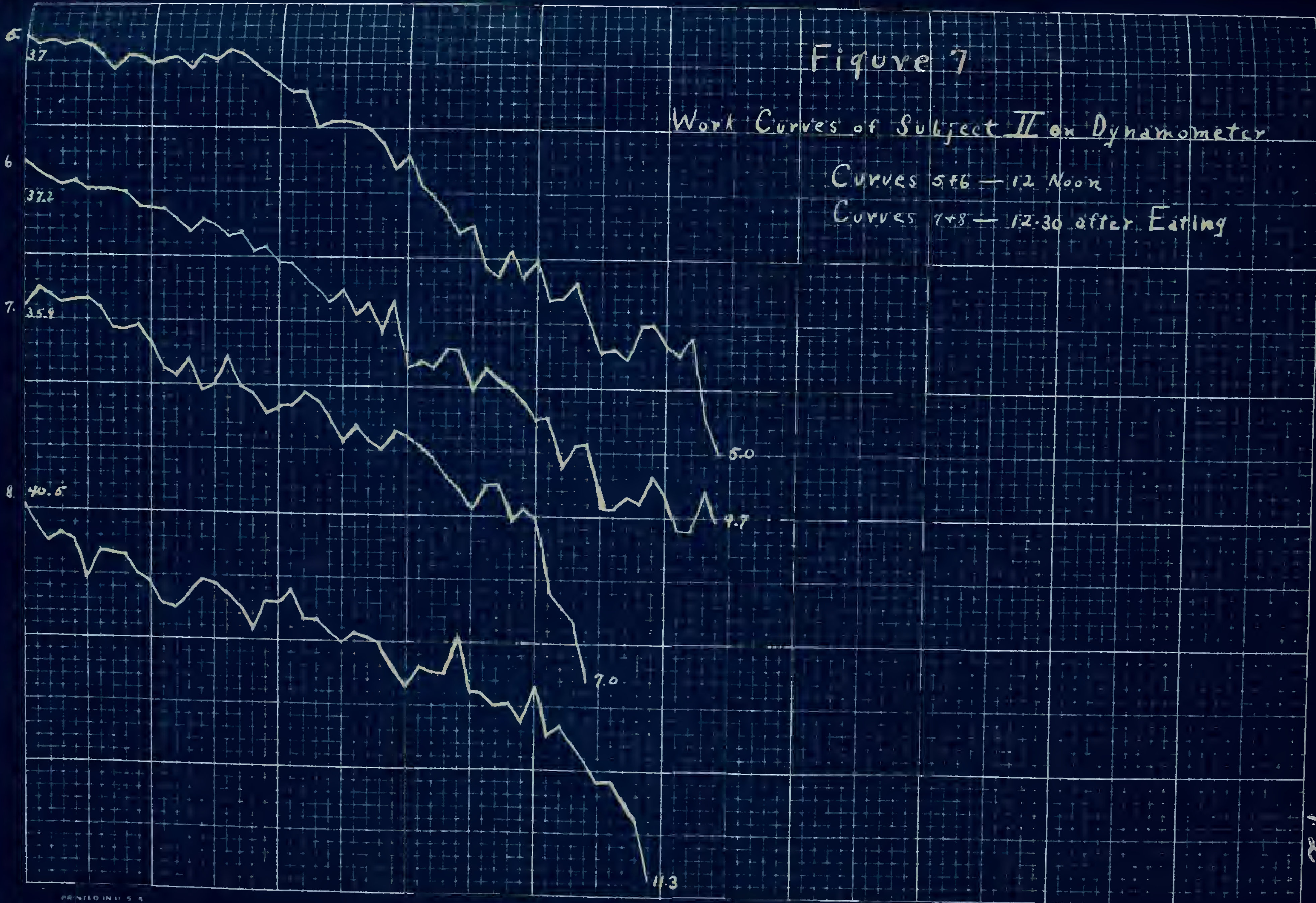



Figure 7

Work Curves of Subject II on Dynamometer

Curves 5+6 — 12 Noon

Curves 7+8 — 12.30 after Eating

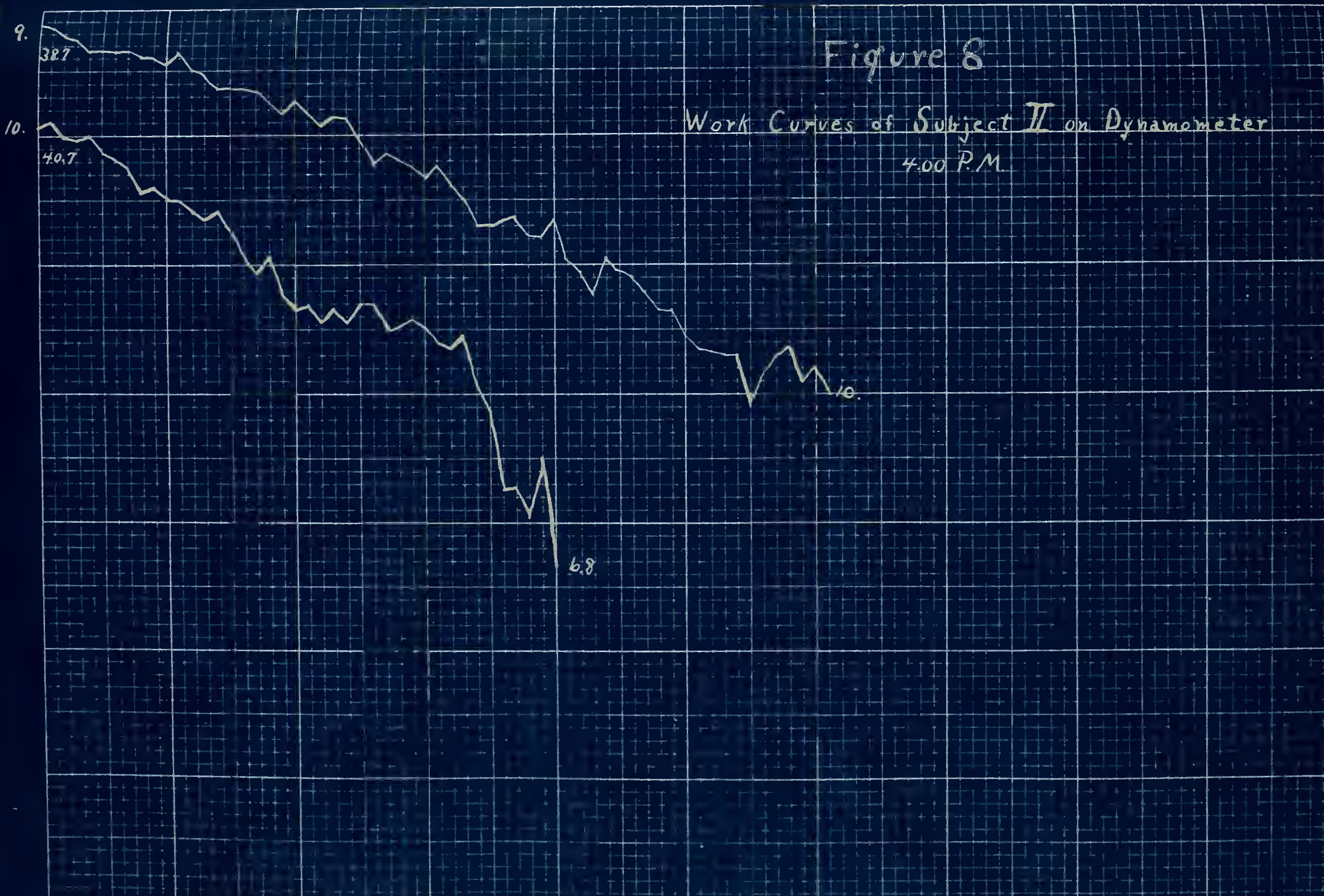


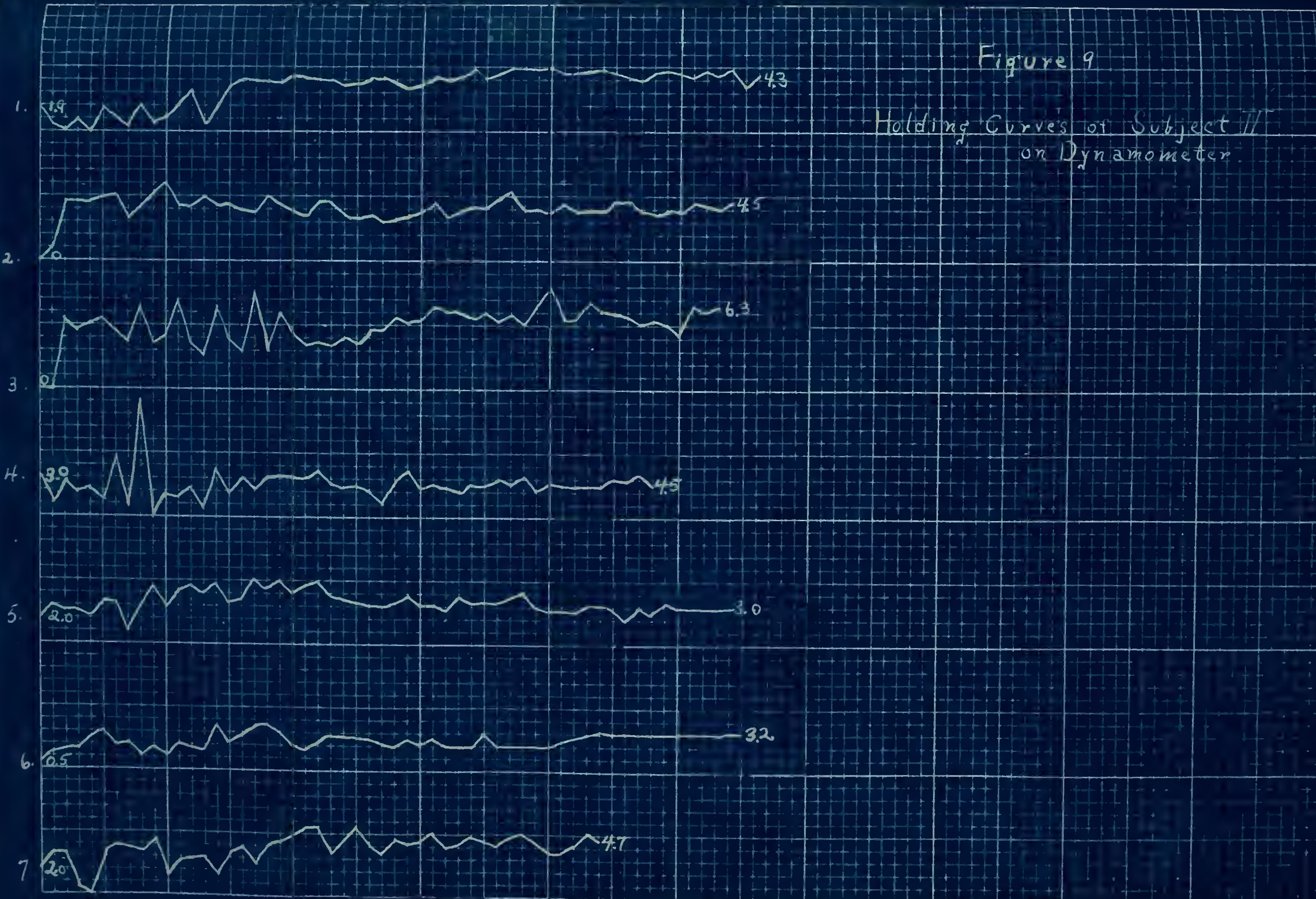

Figure 8

Work Curves of Subject II on Dynamometer

4.00 P.M.

# Figure 9

Holding Curves of Subject II
on Dynamometer



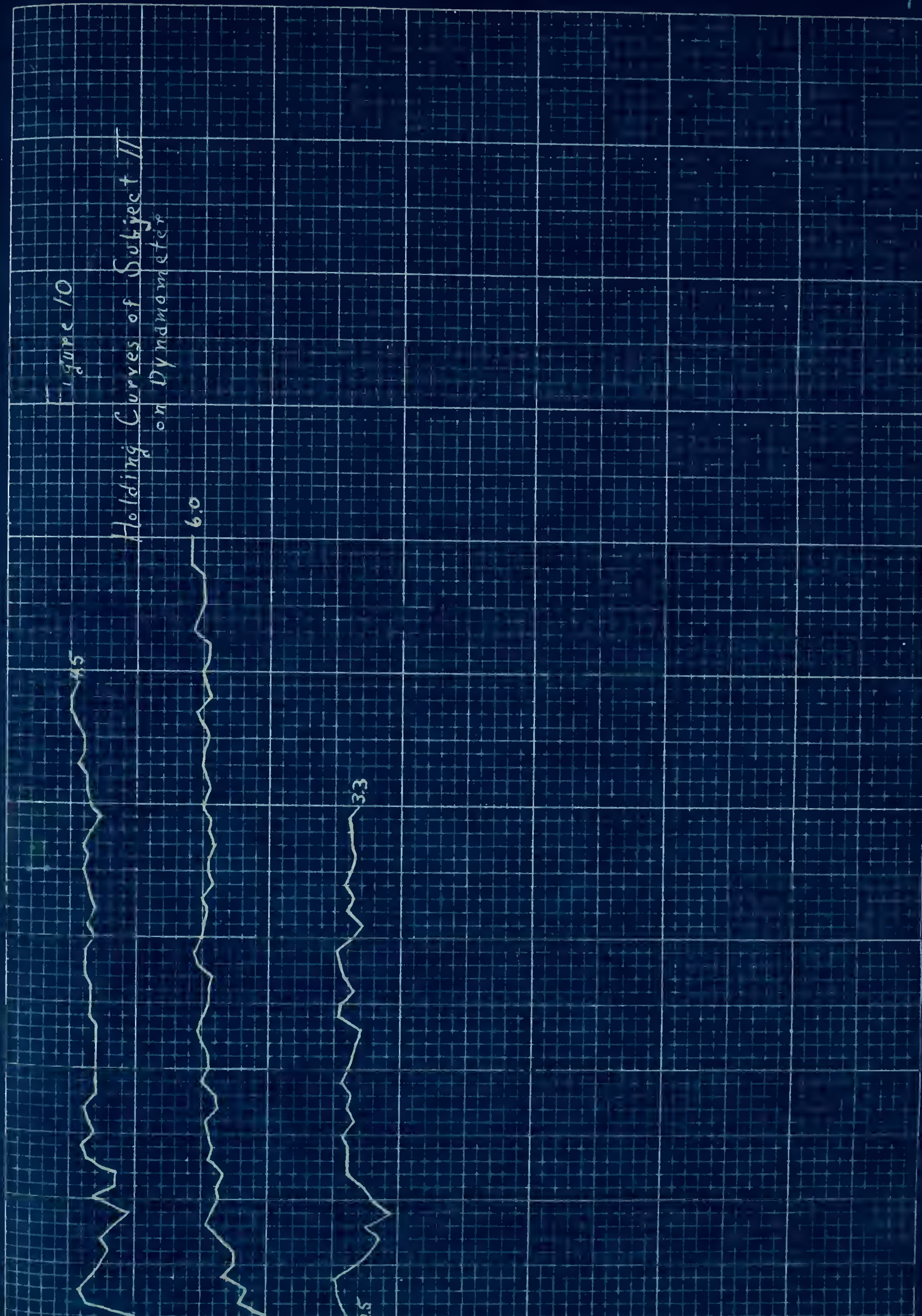


Figure 10
Holding Curves of Subject II
on Dynamometer
8.
9.
10.
0
4.5
0
6.0
2.5
3.3

Figure 11

Work Curves of Subject III on Dynamometer

12 Noon

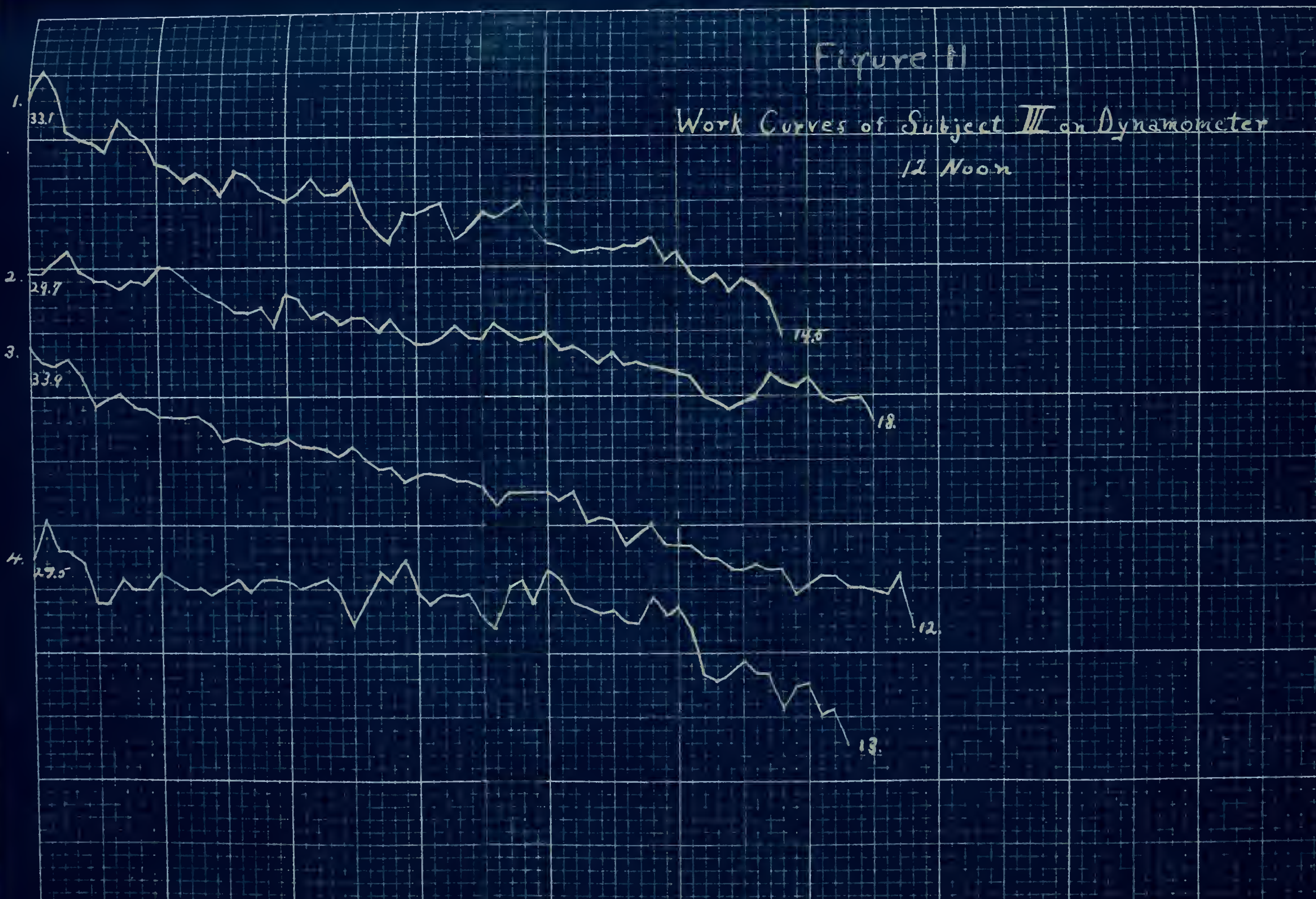



Figure 12
Work Curves of Subject III on Dynamometer
1.00 P.M. after Eating

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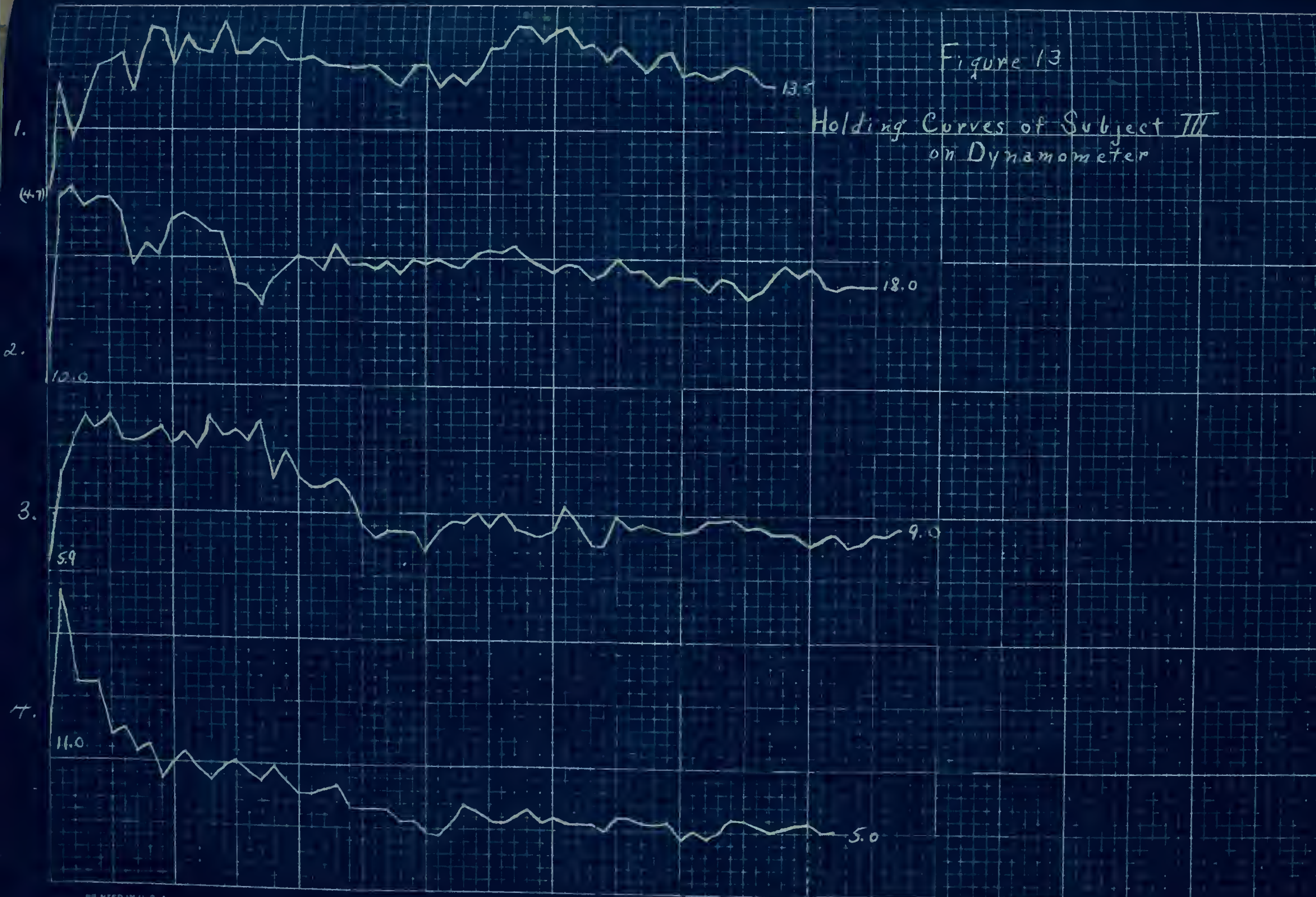
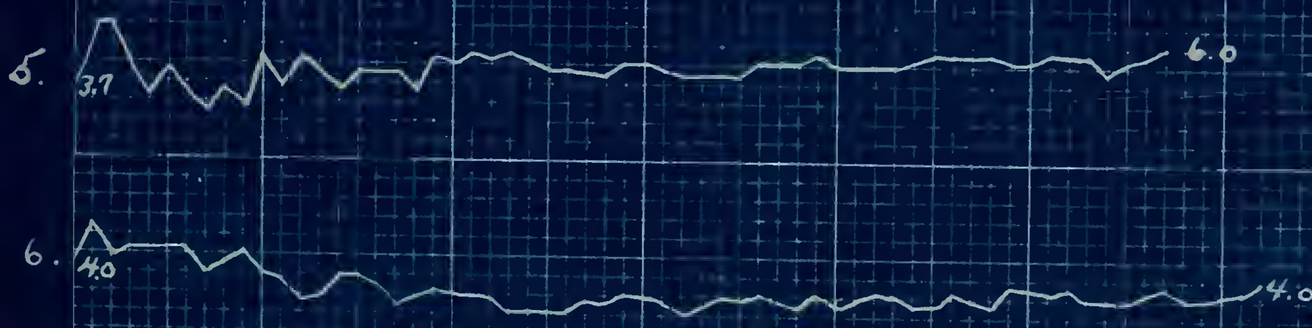



Figure 13
Holding Curves of Subject III on Dynamometer

Figure 14

Holding Curves of Subject III
on Dynamometer



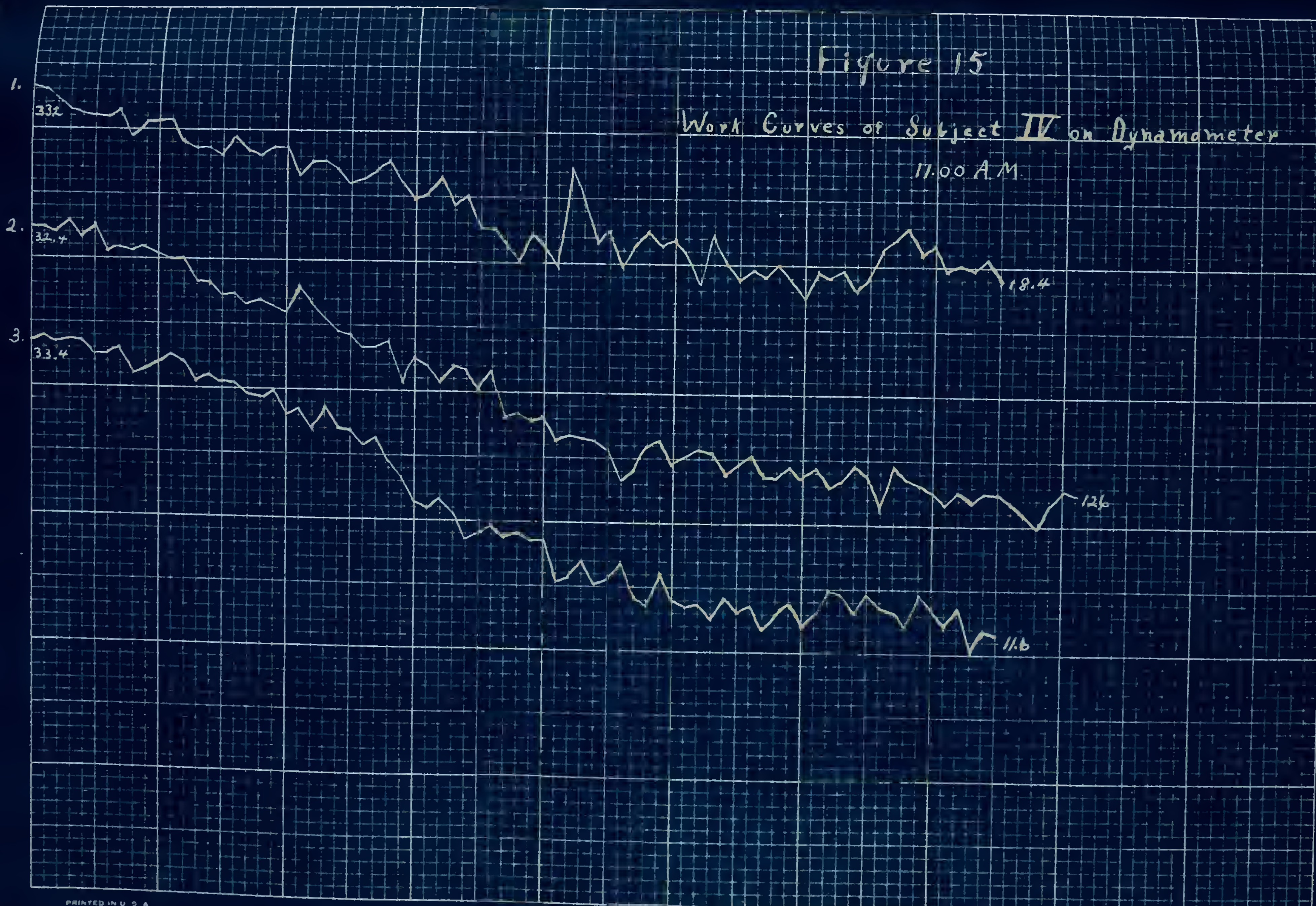



Figure 15

Work Curves of Subject IV on Dynamometer

11.00 A.M.

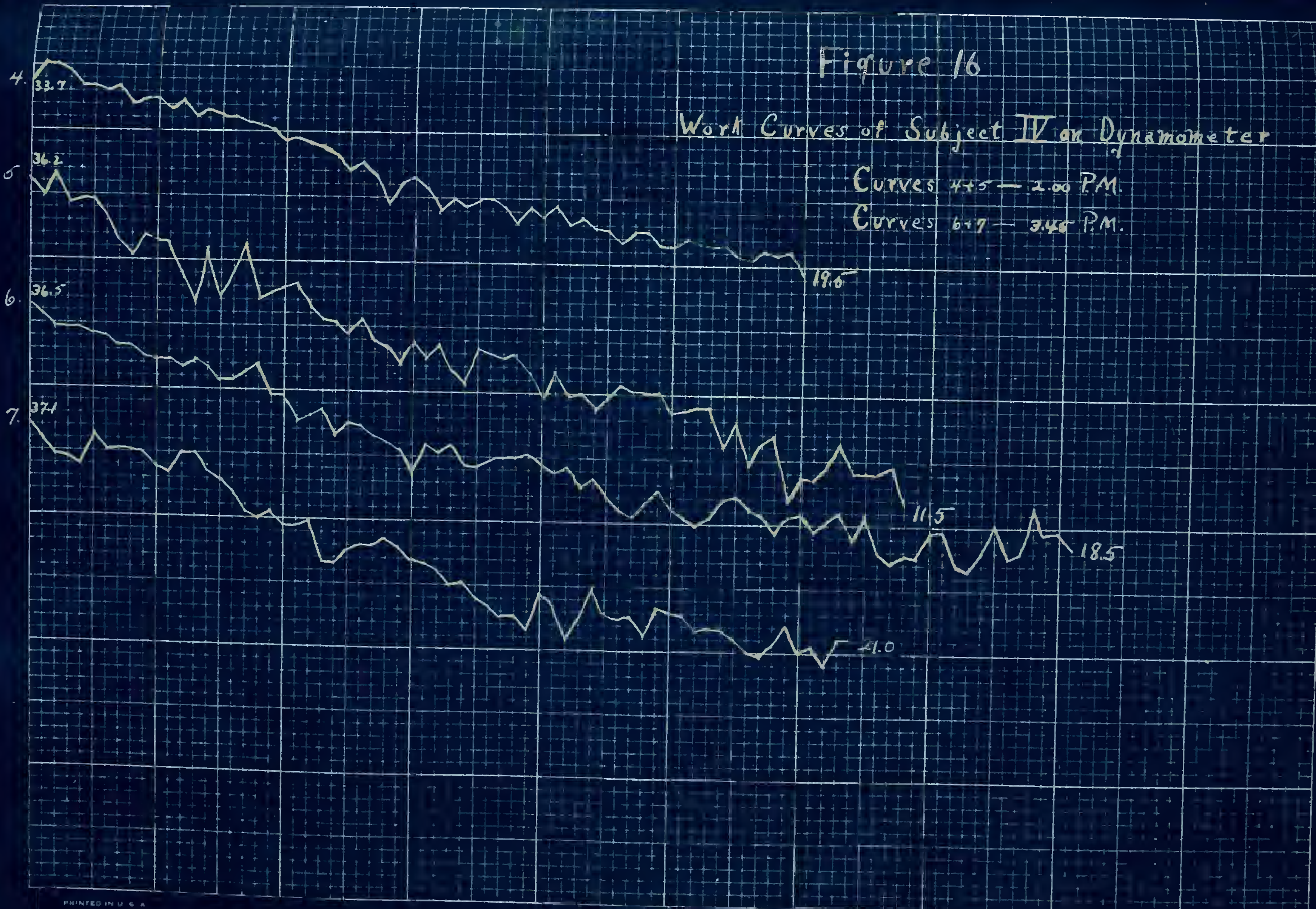



Figure 16

Work Curves of Subject IV on Dynamometer

Curves 4+5 — 2.00 P.M.

Curves 6+7 — 3.45 P.M.

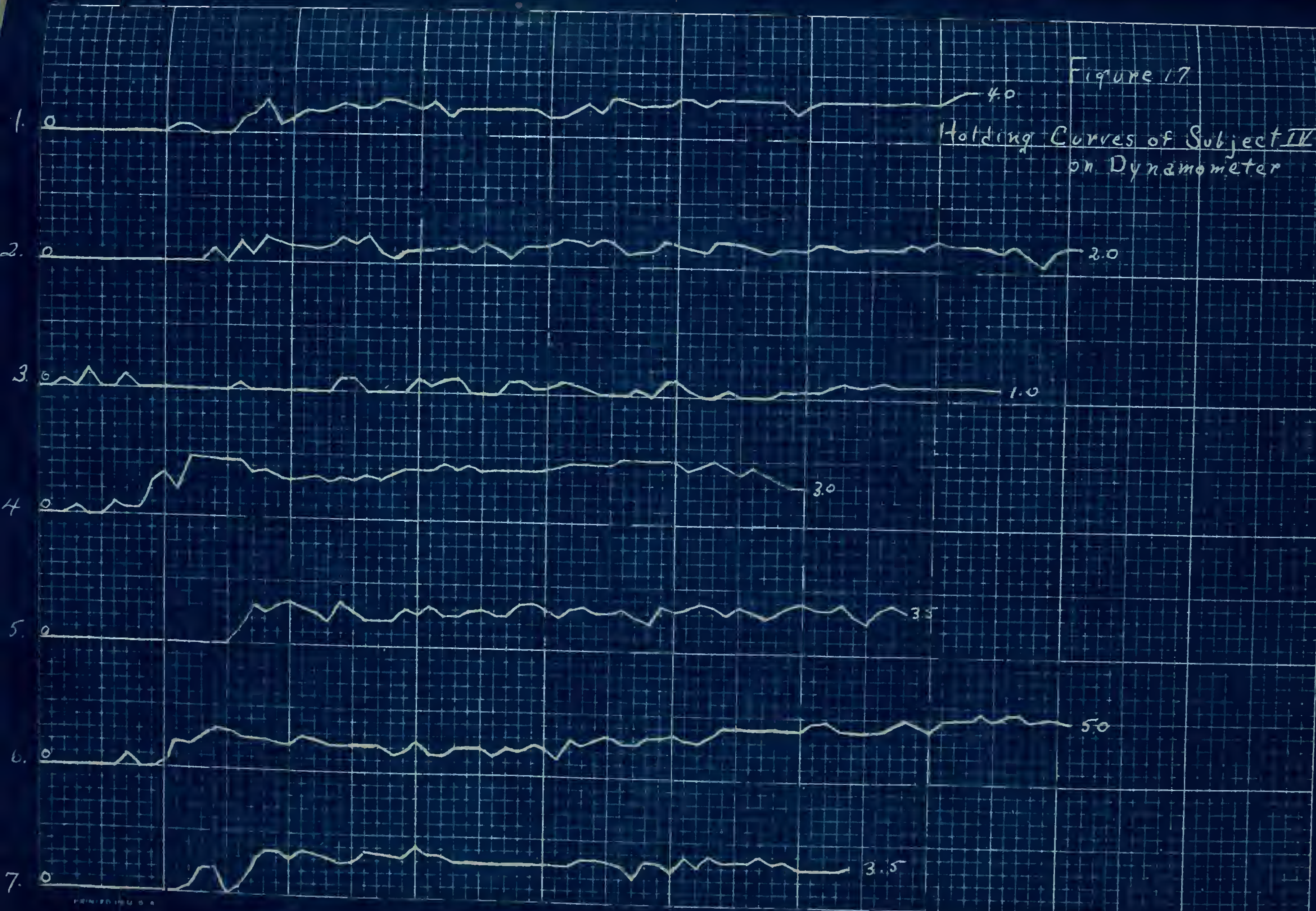


Figure 17
Holding Curves of Subject IV
on Dynamometer
1.
0
4.0
2.
0
2.0
3.
0
1.0
4
0
3.0
5.
0
3.5
6.
0
5.0
7.
0
3.5

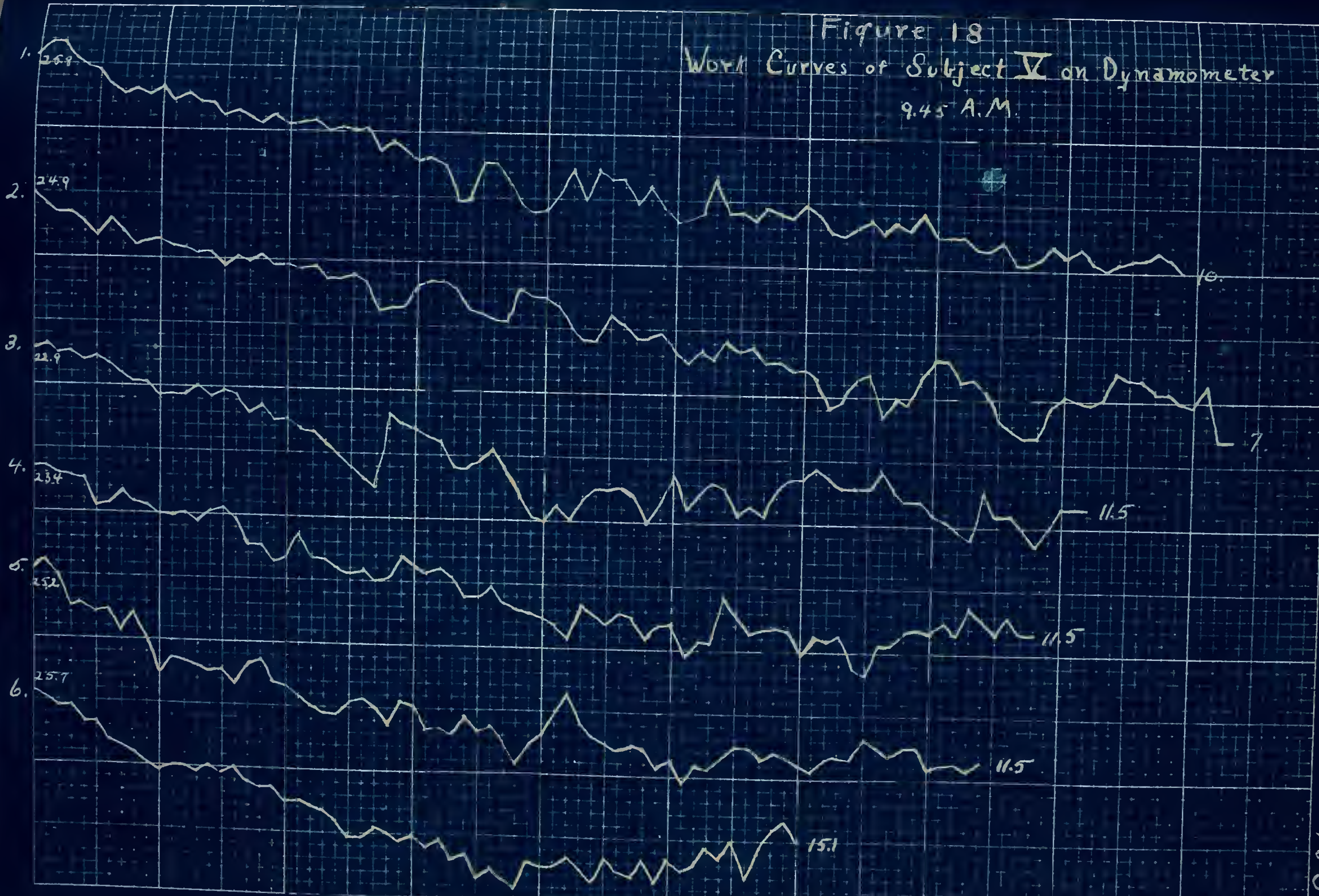
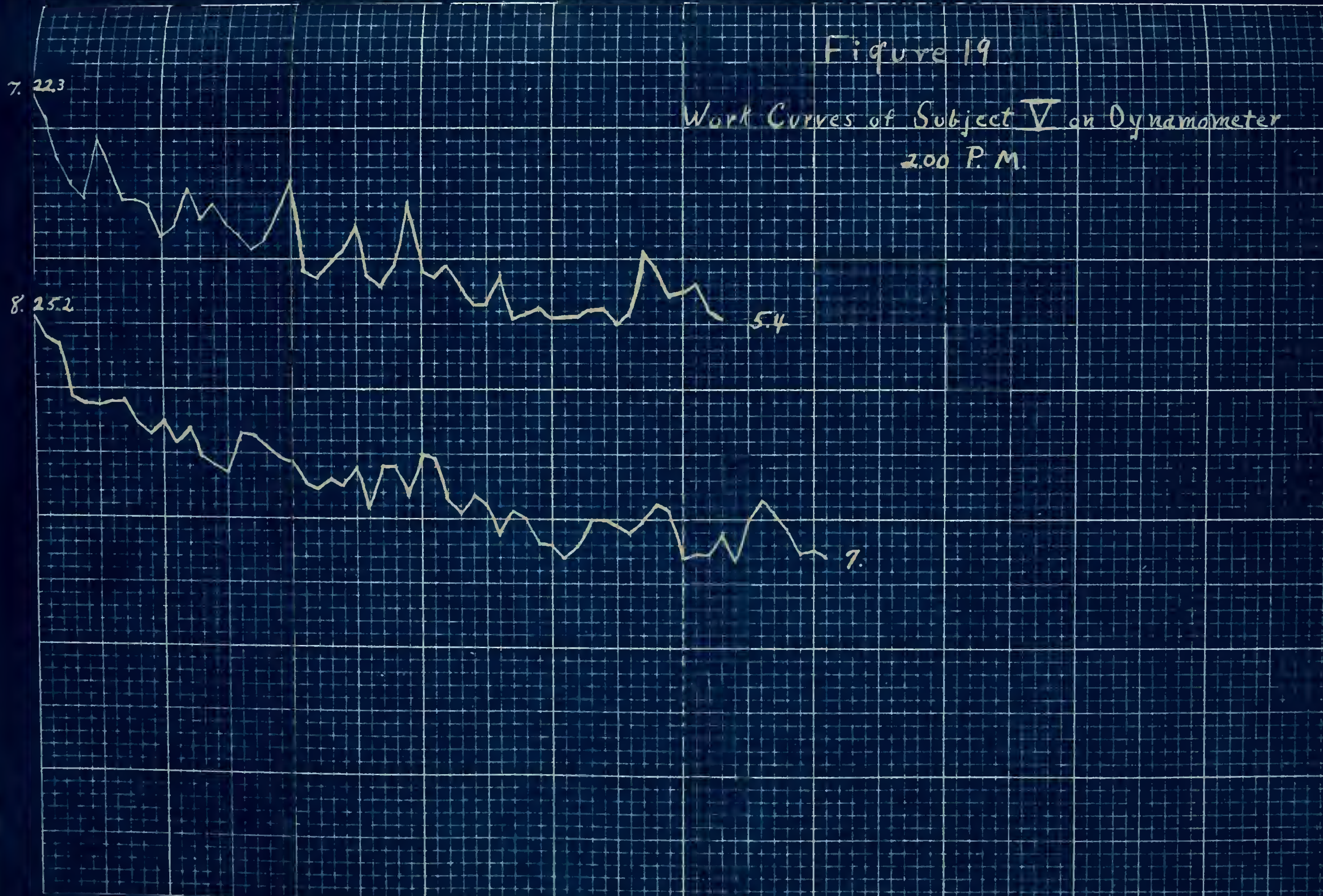



Figure 18
Work Curves of Subject V on Dynamometer
9.45 A.M.

Figure 19

Work Curves of Subject V on Dynamometer
2.00 P. M.



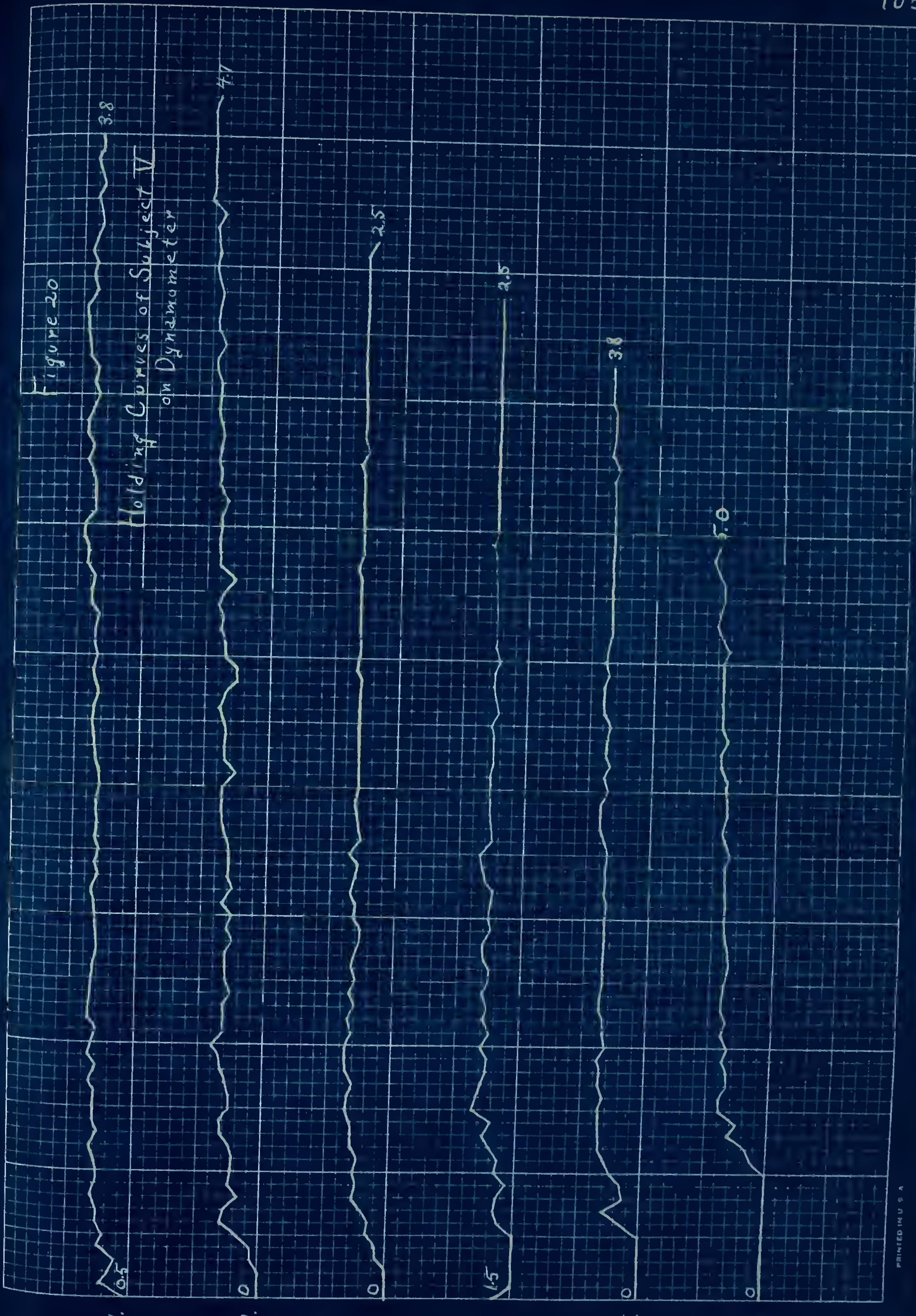


Figure 20
Holding Curves of Subject V
on Dynamometer
1.
0.5
3.8
2.
0
4.1
3.
0
2.5
4.
1.5
2.5
5.
0
3.8
6.
0
5.0

Fig. 21

Holding Curves of Subject V
on Dynamometer

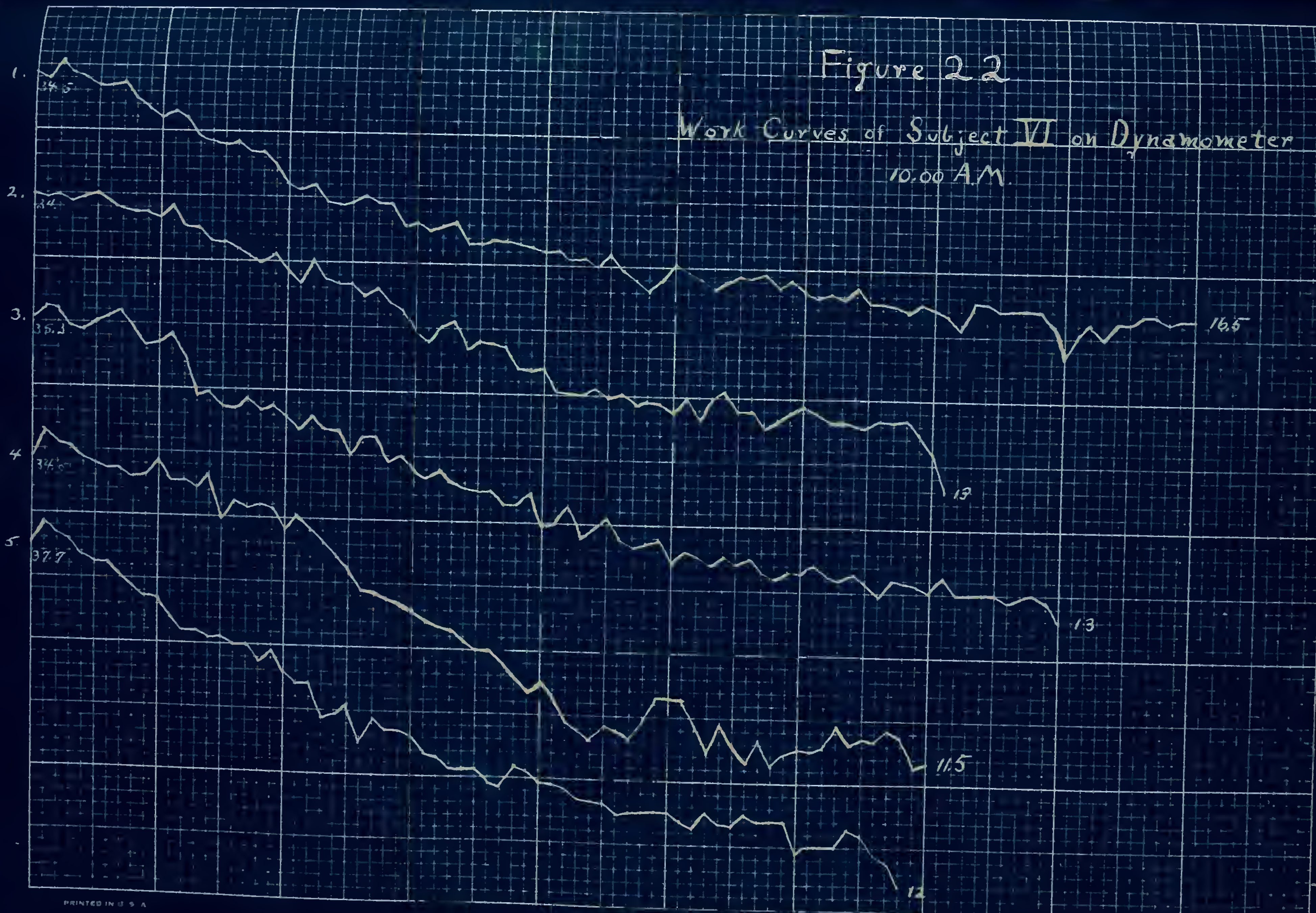



Figure 22

Work Curves of Subject VI on Dynamometer
10.00 A.M.

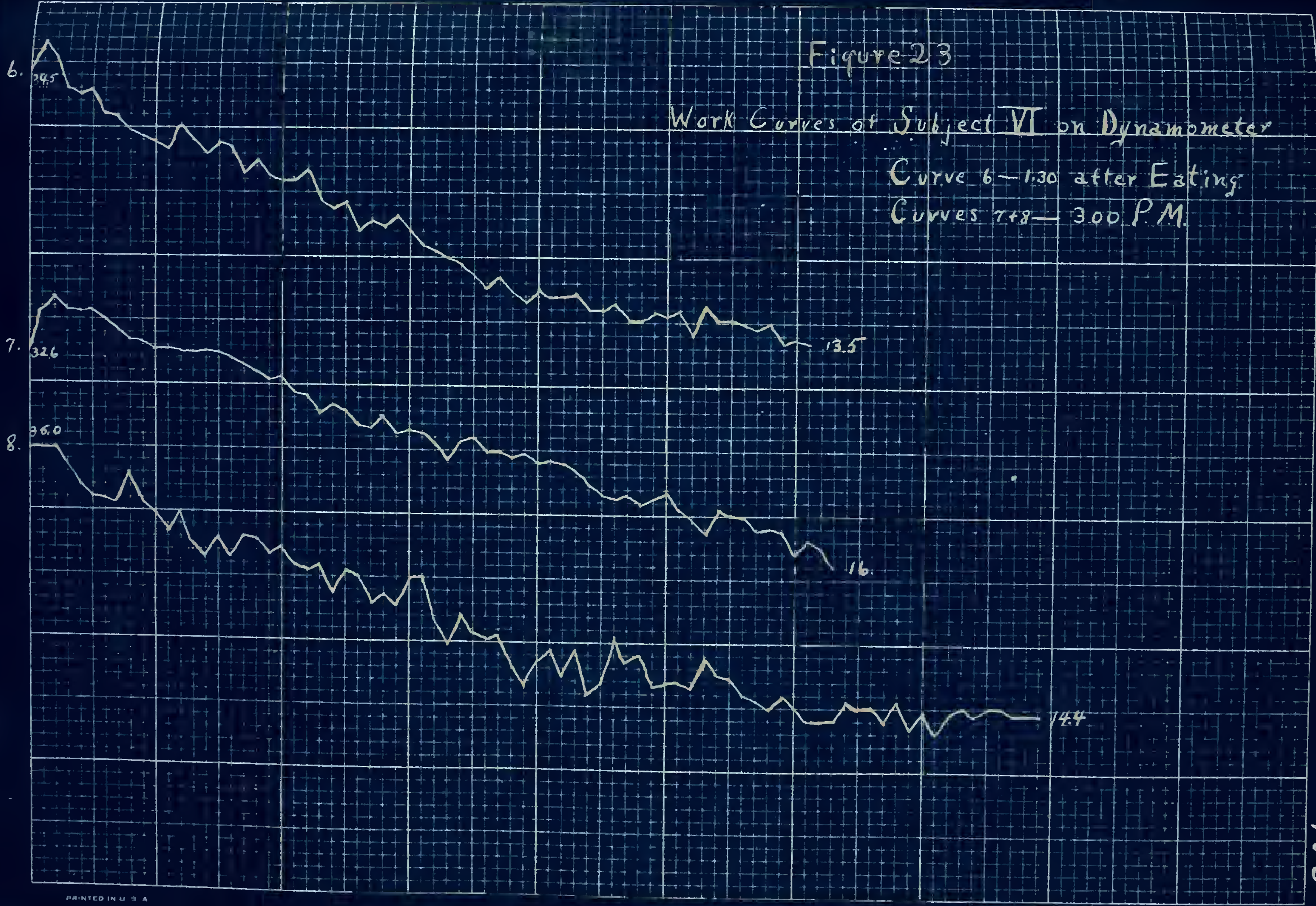



Figure 23

Work Curves of Subject VI on Dynamometer

Curve 6 — 1.30 after Eating

Curves 7+8 — 3.00 P.M.

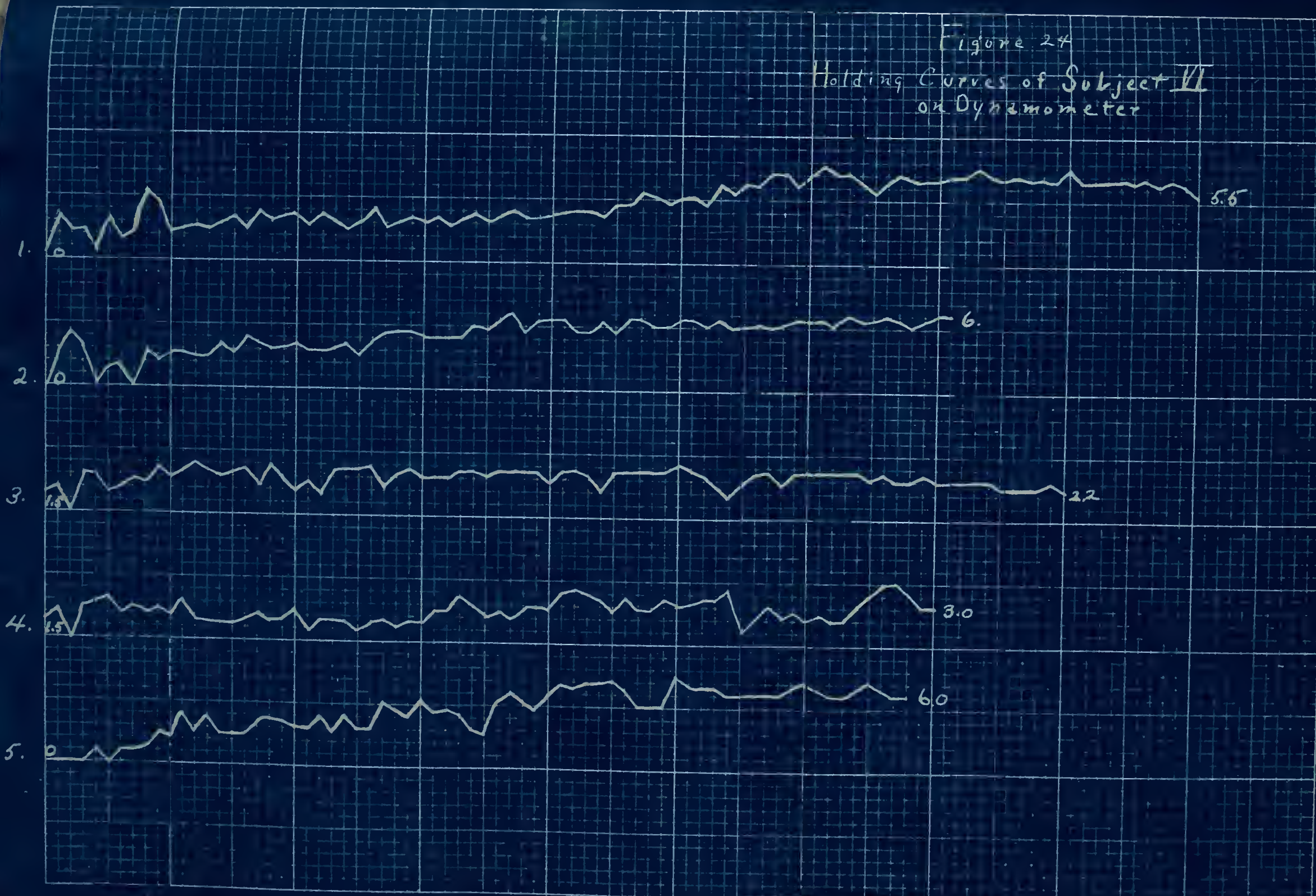



Figure 24
Holding Curves of Subject VI
on Dynamometer

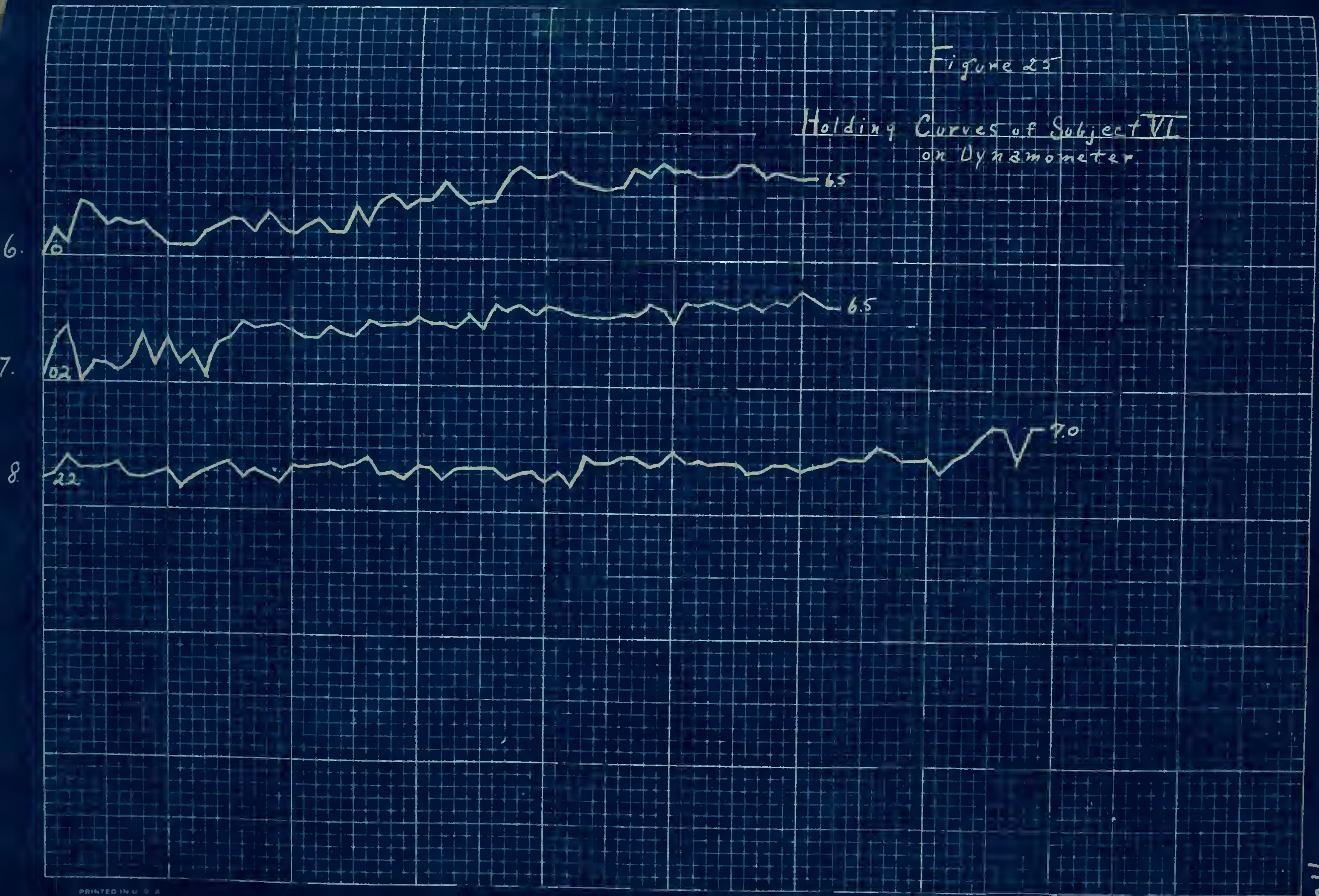



Figure 25

Holding Curves of Subject VI on Dynamometer.

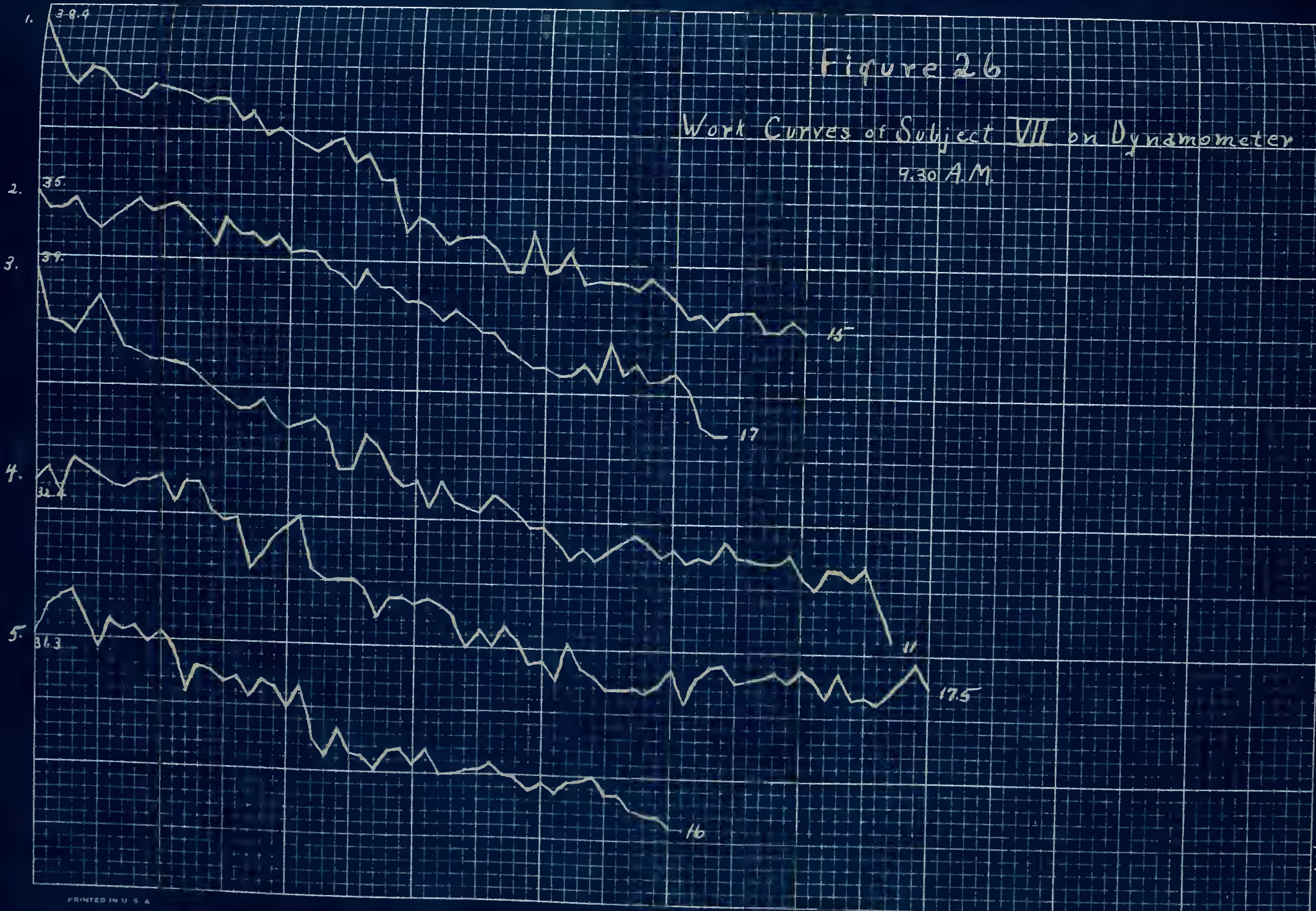



Figure 26

Work Curves of Subject VII on Dynamometer

9.30 A.M.

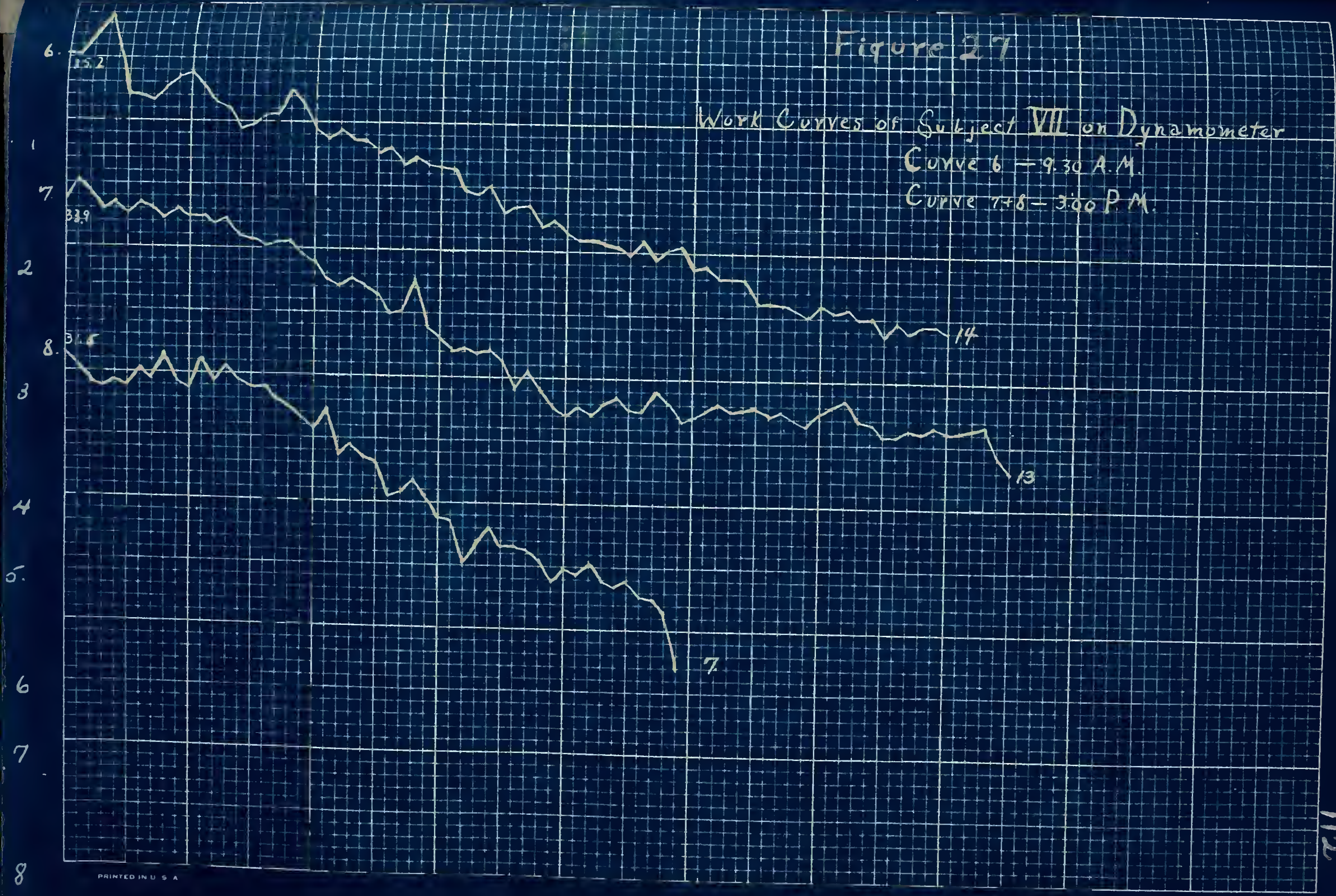



Figure 27

Work Curves of Subject VII on Dynamometer

Curve 6 — 9.30 A.M.

Curve 7+8 — 3.00 P.M.

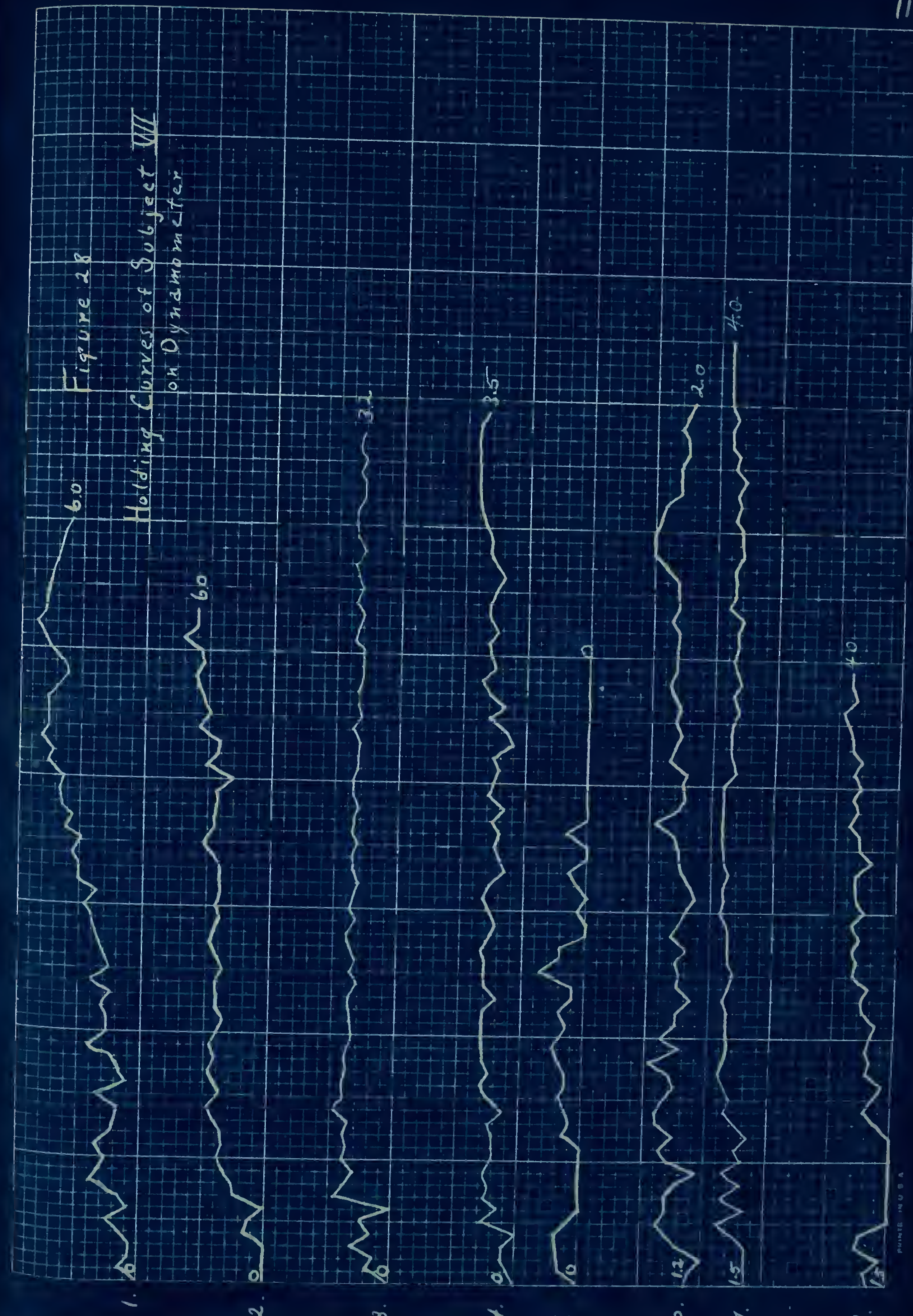


Figure 28
Holding Curves of Subject VIII
on Dynamometer
1.
2.
3.
4.
5.
6.
7.
8.
6.0
6.0
3.1
3.5
2.0
4.0
4.0
1.2
1.5
1.3


Figure 29

Work Curves of Subject VIII on Dynamometer

Curves 1 to 4 — 9.45 A.M.

Curves 5 & 6 — 2.00 P.M.

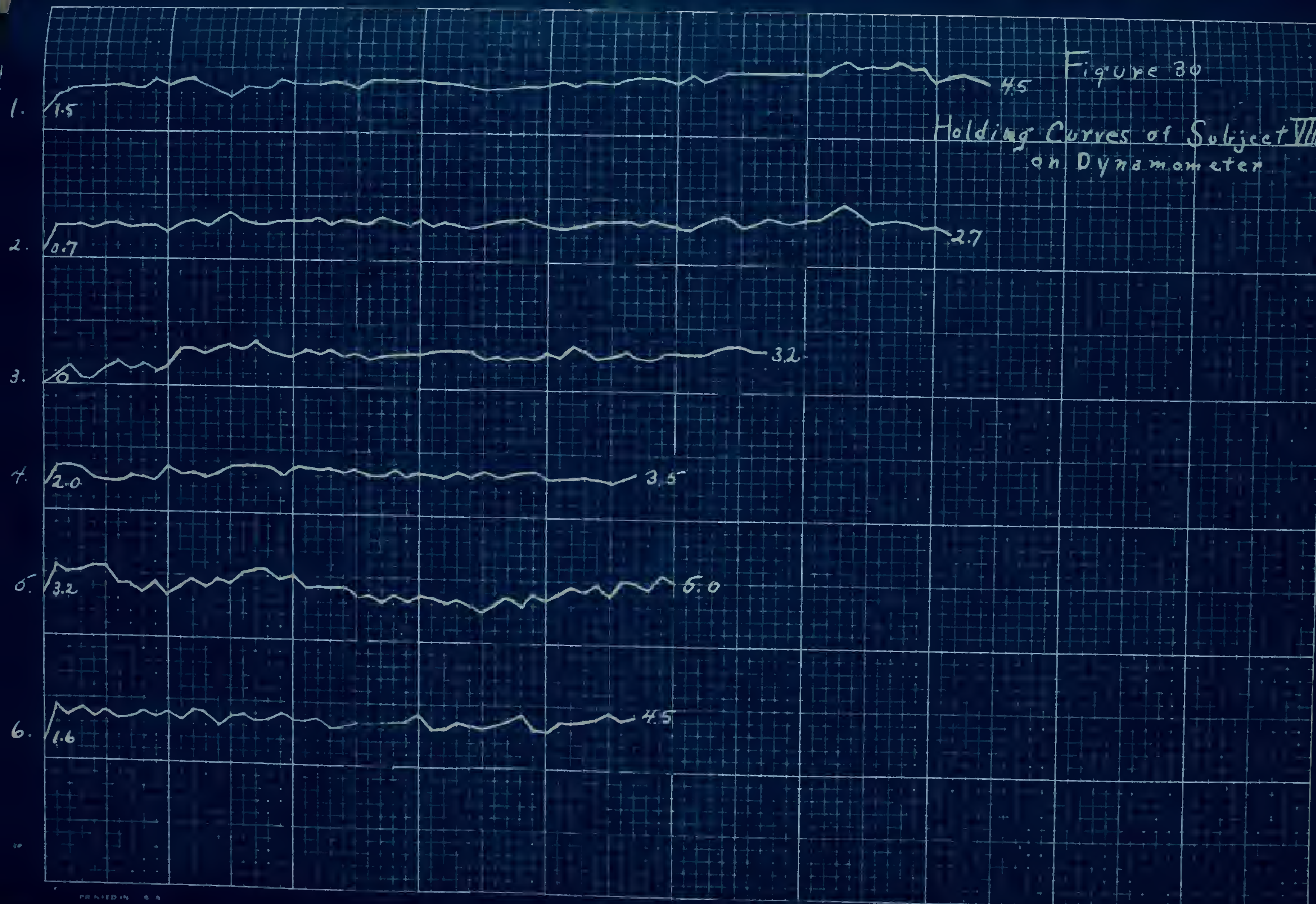


Figure 30
Holding Curves of Subject VIII on Dynamometer
1.
1.5
4.5
2.
0.7
2.7
3.
0
3.2
4.
2.0
3.5
5.
3.2
6.0
6.
1.6
4.5

Figure 31

Work Curves of Subject IX on Dynamometer

10 30 A.M

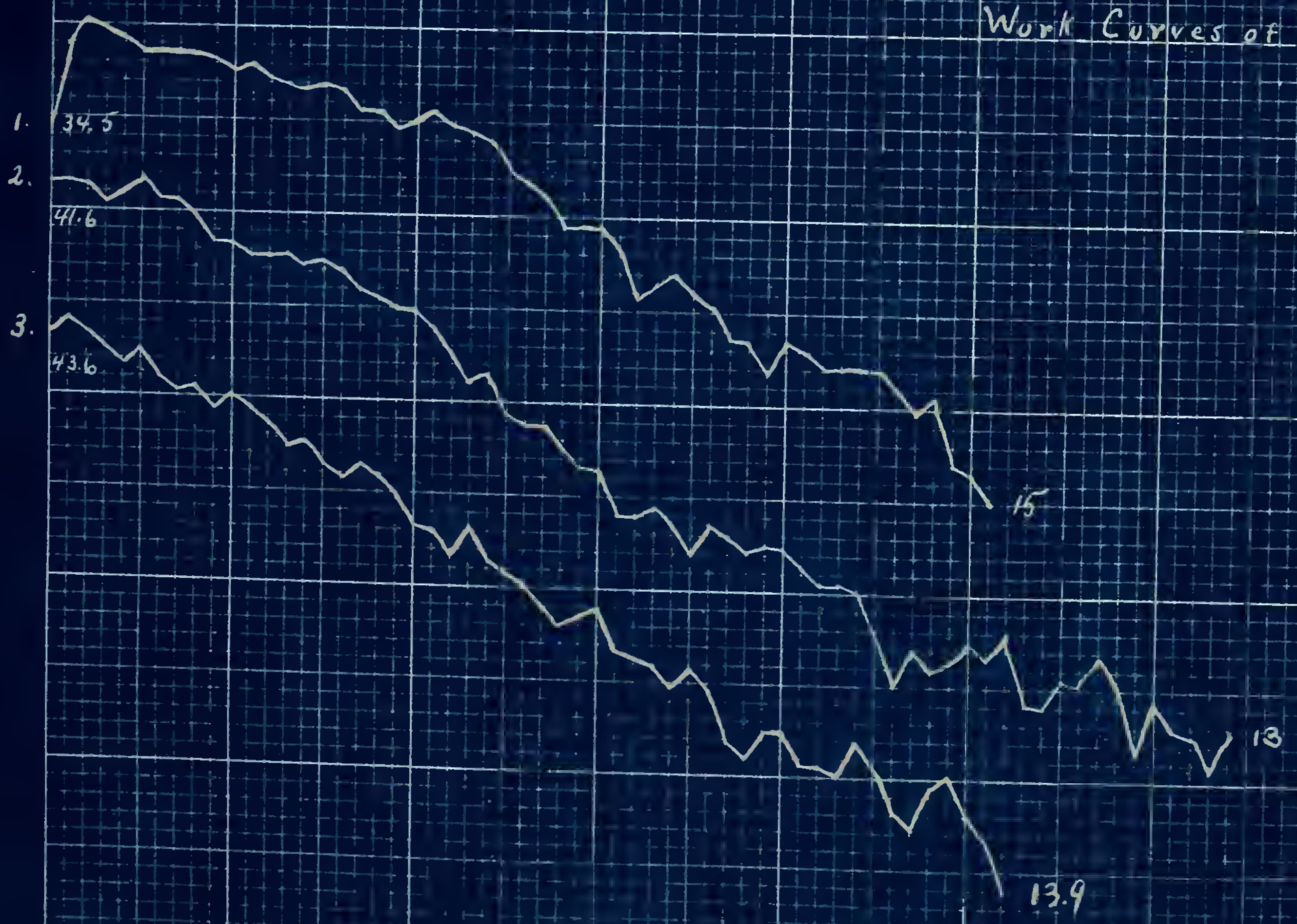



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Figure 32

Work Curves of Subject IX on Dynamometer
3.00 PM.

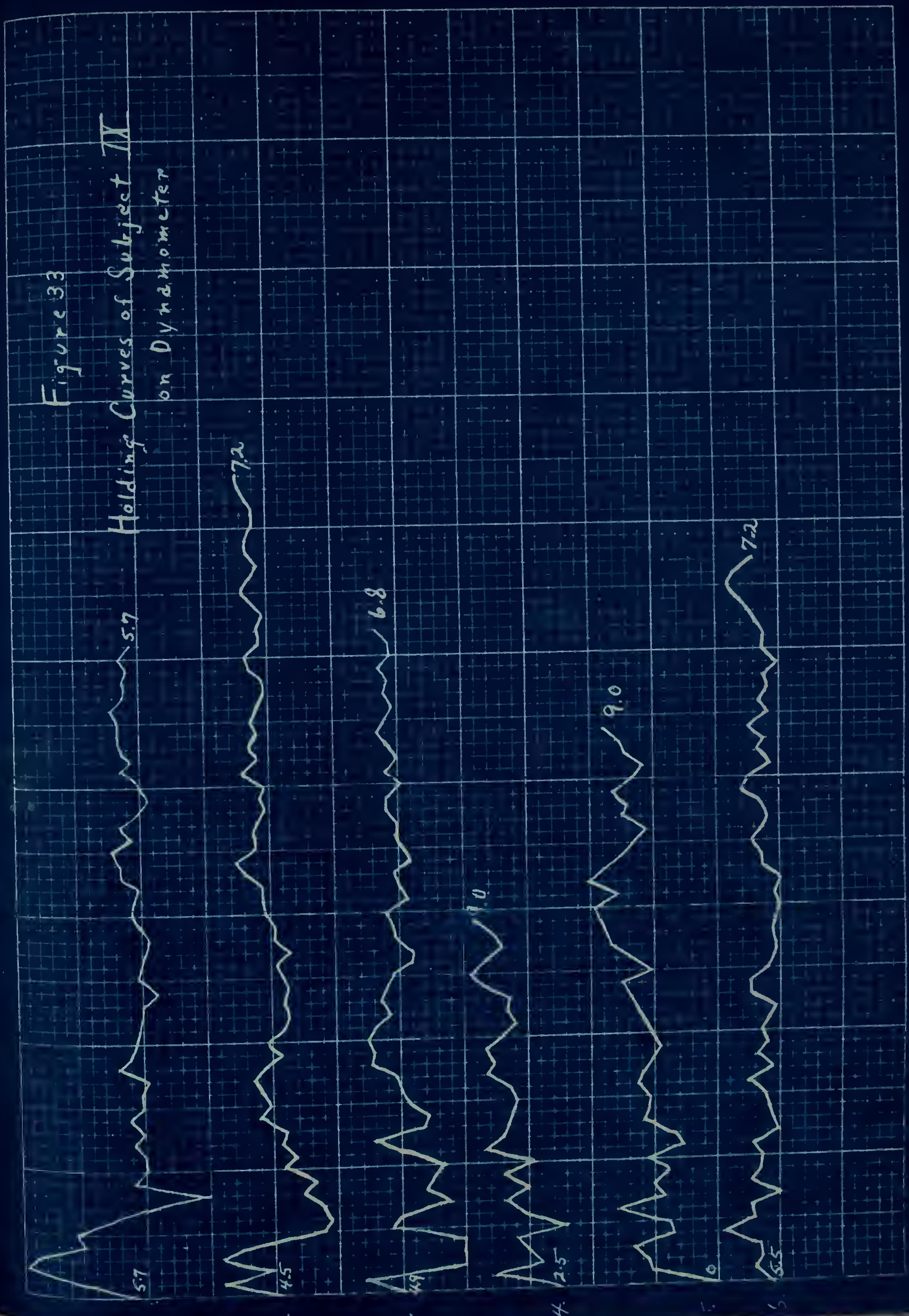



Figure 33
Holding Curves of Subject IX on Dynamometer

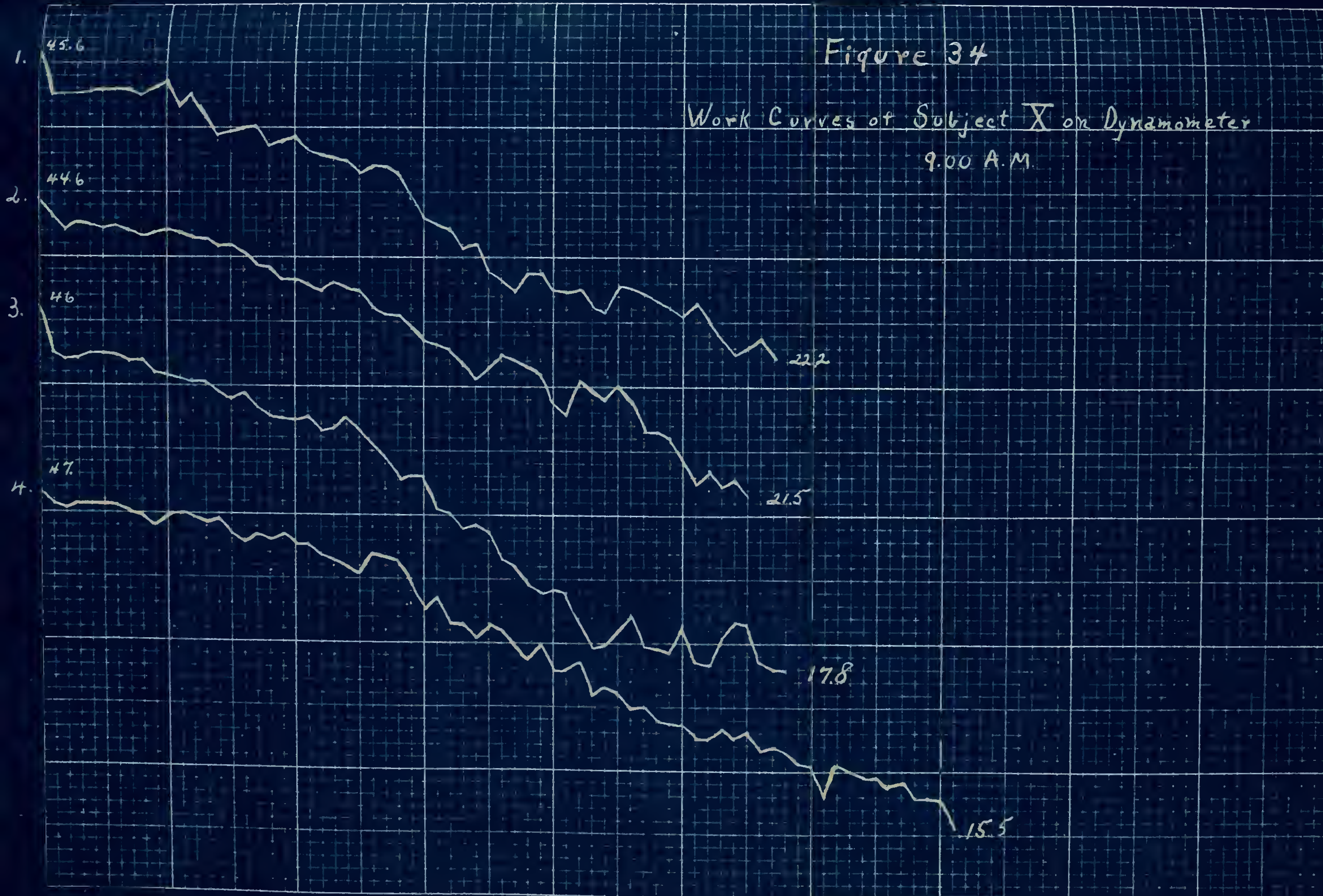



Figure 34

Work Curves of Subject X on Dynamometer

9.00 A.M.

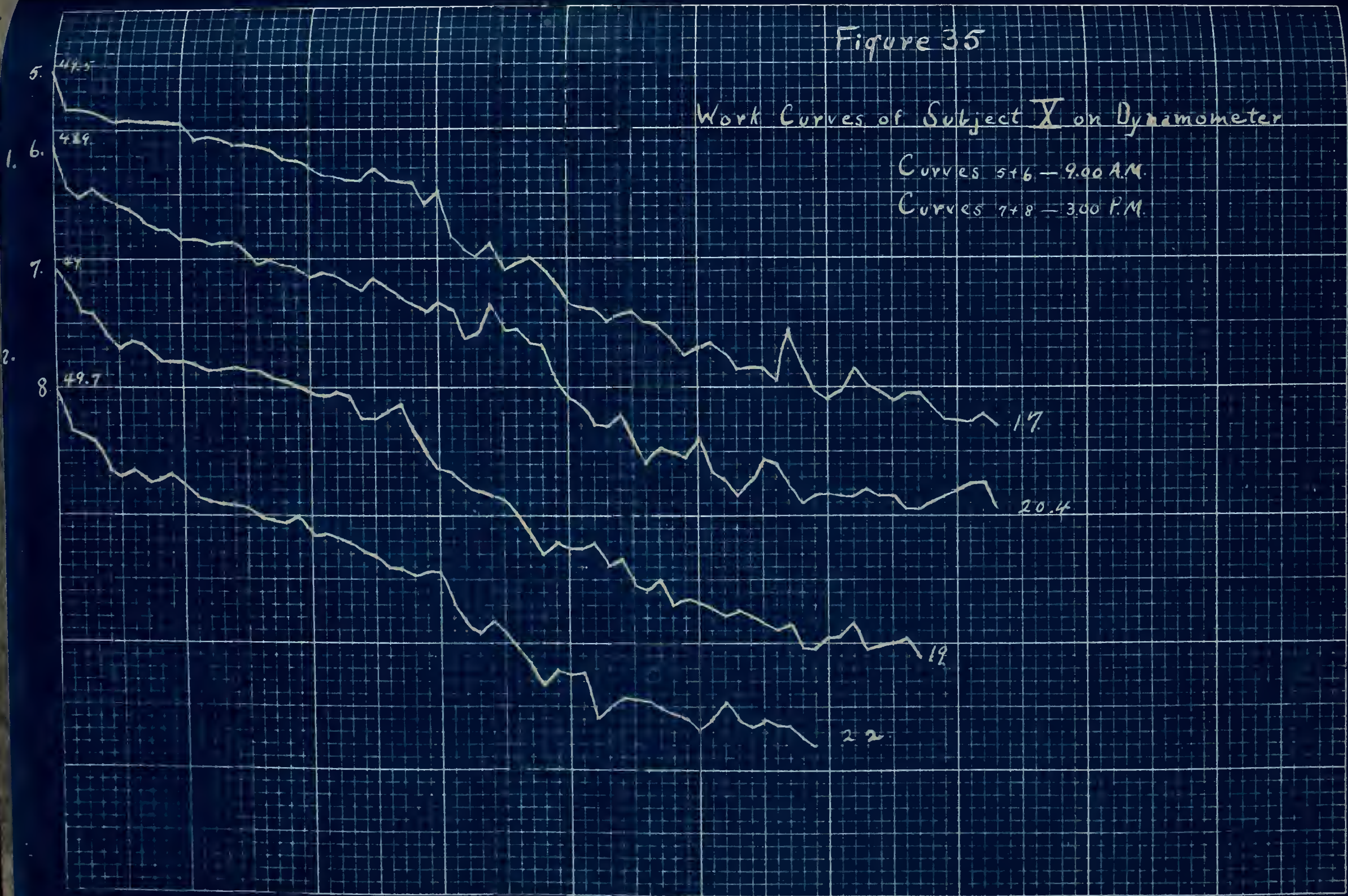


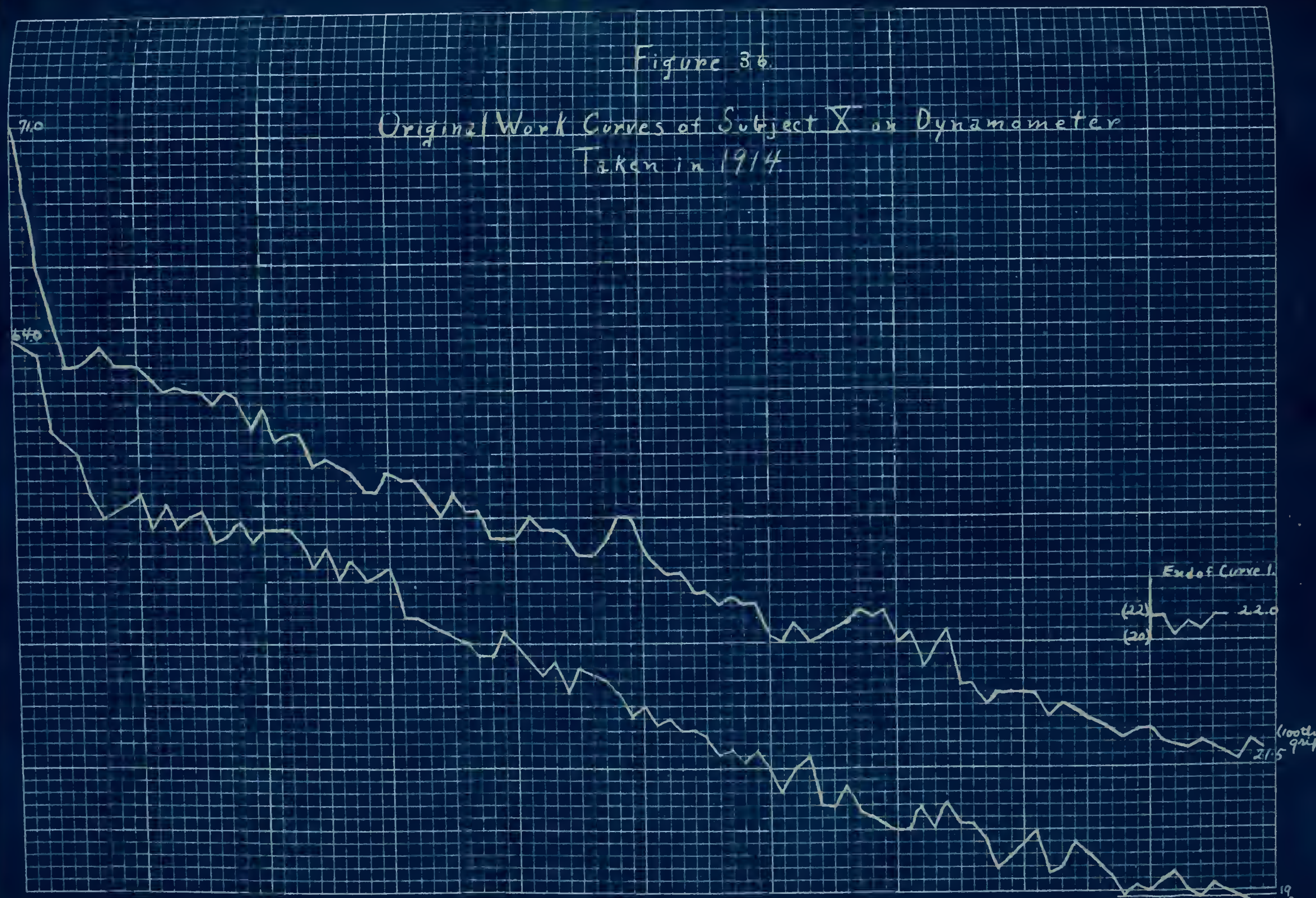

Figure 35

Work Curves of Subject X on Dynamometer

Figure 36.

Original Work Curves of Subject X on Dynamometer

Taken in 1914



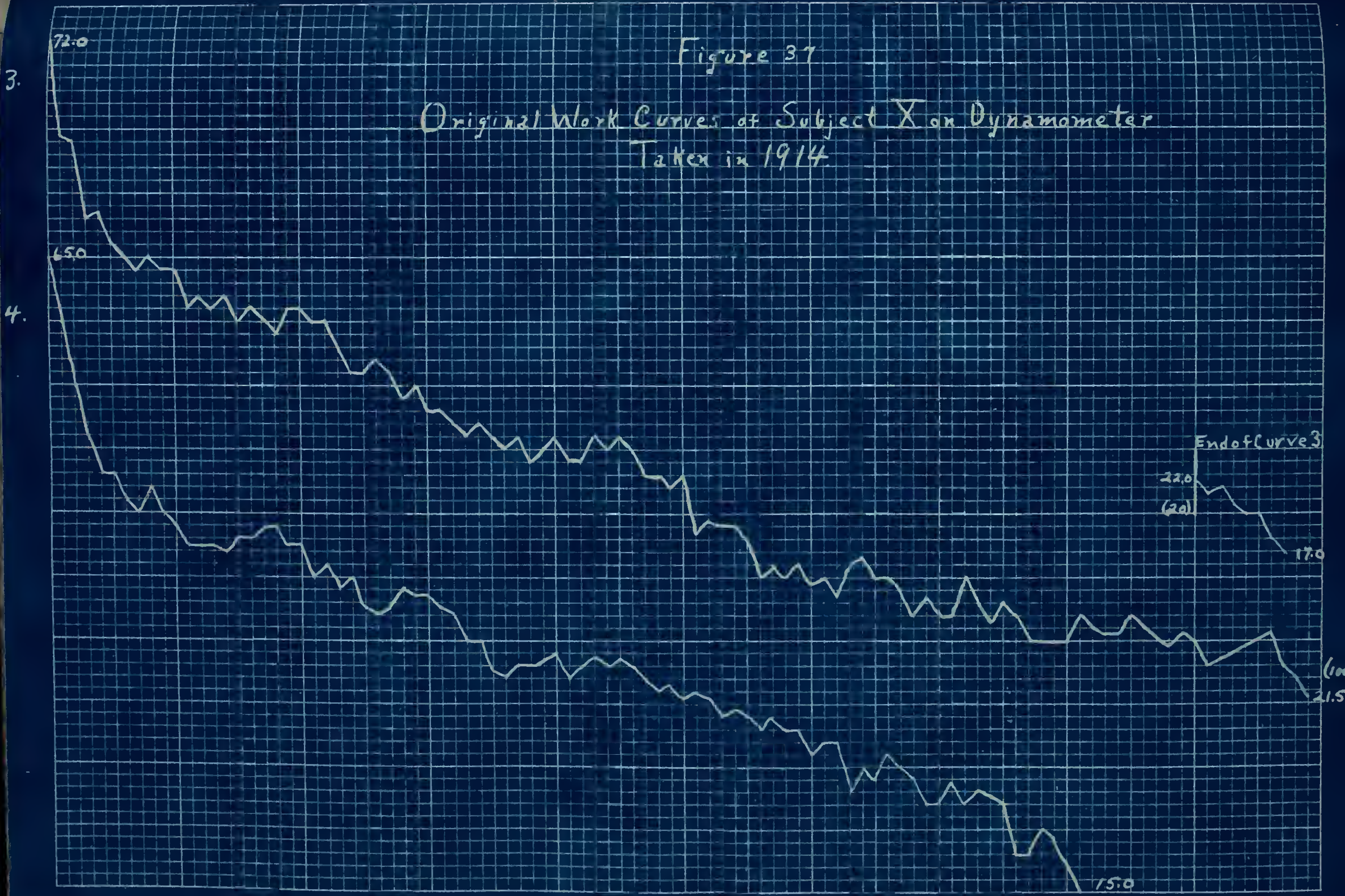



Figure 31

Original Work Curves of Subject X on Dynamometer Taken in 1914

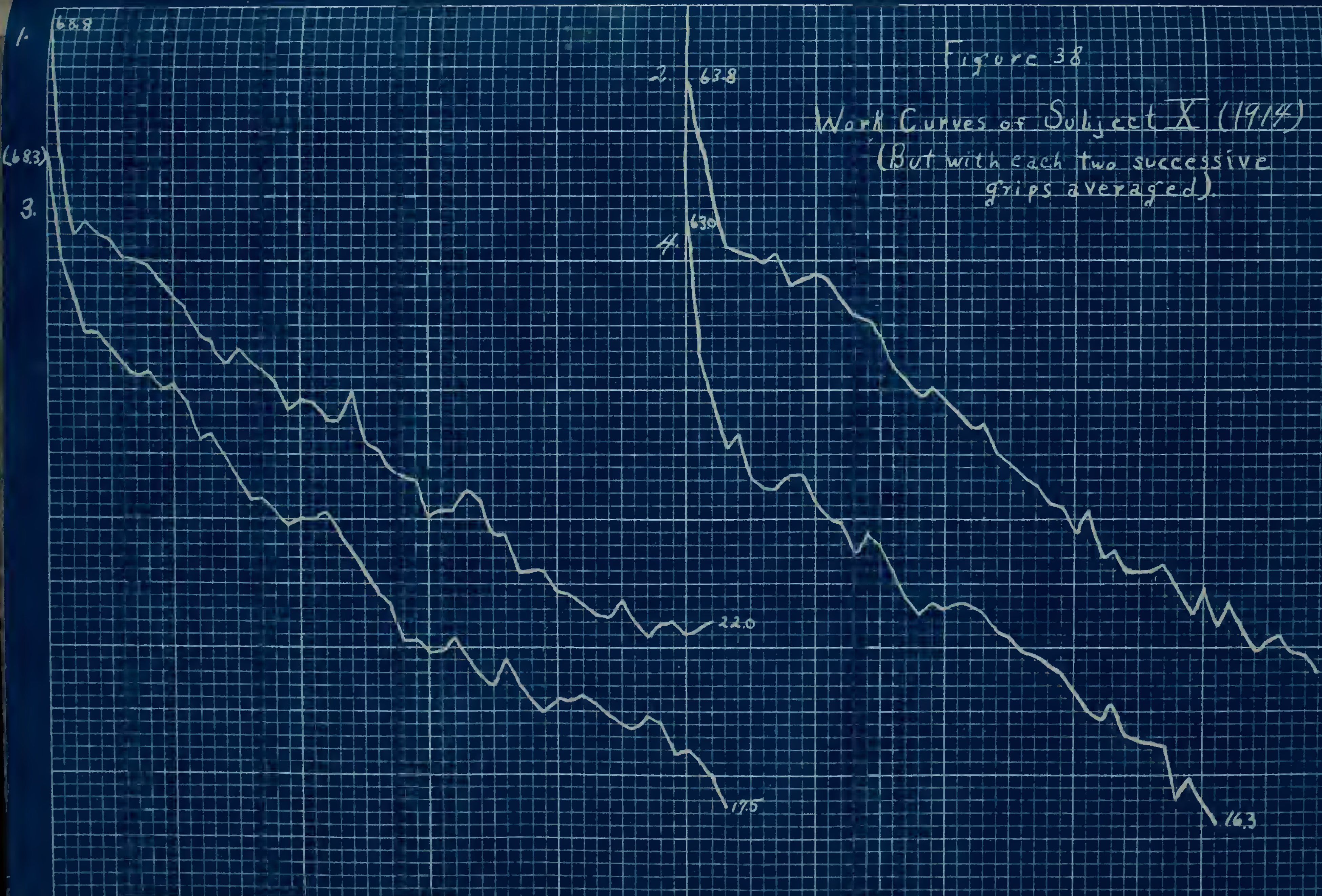



Figure 38

Work Curves of Subject X (1914)
(But with each two successive grips averaged).

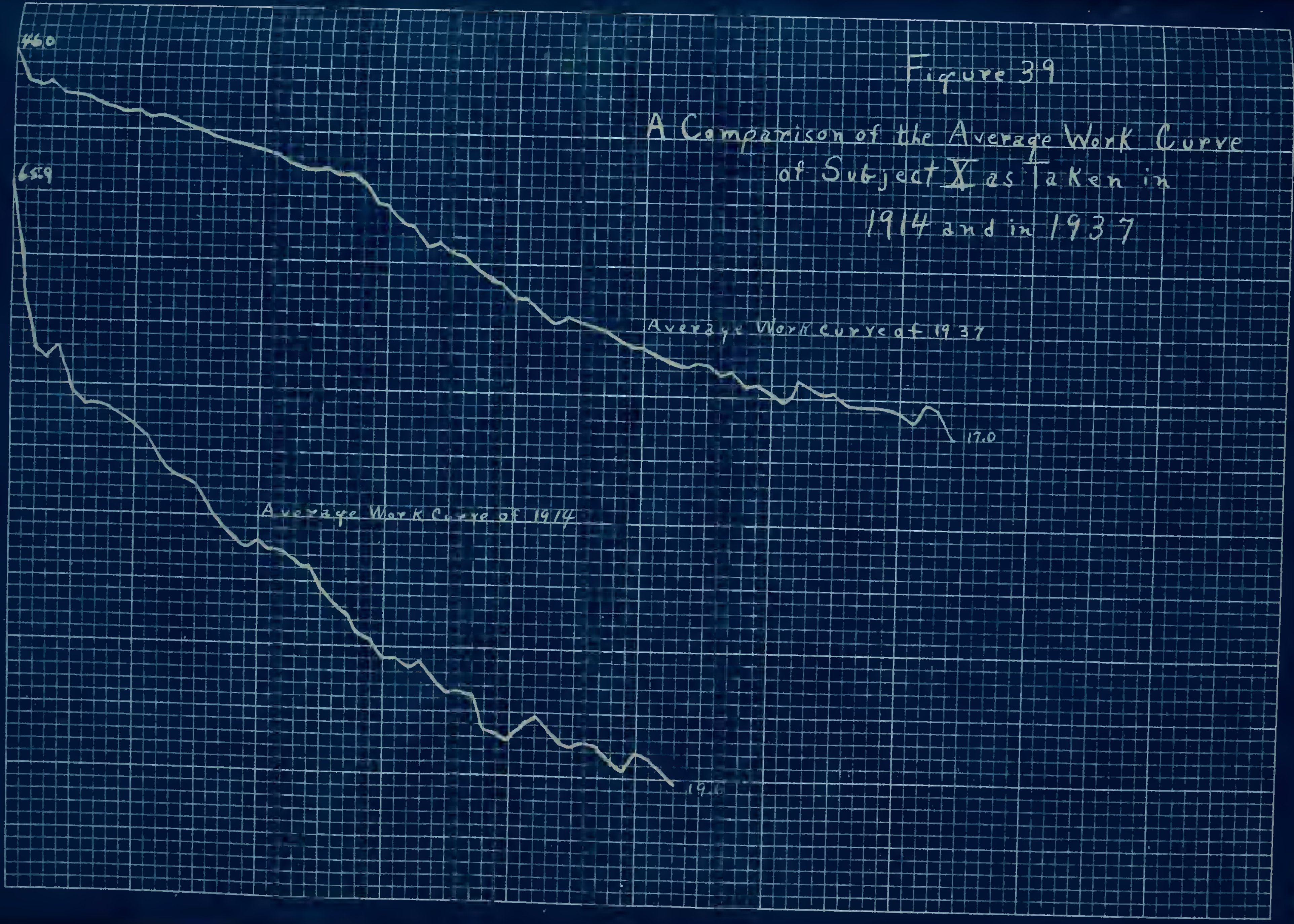
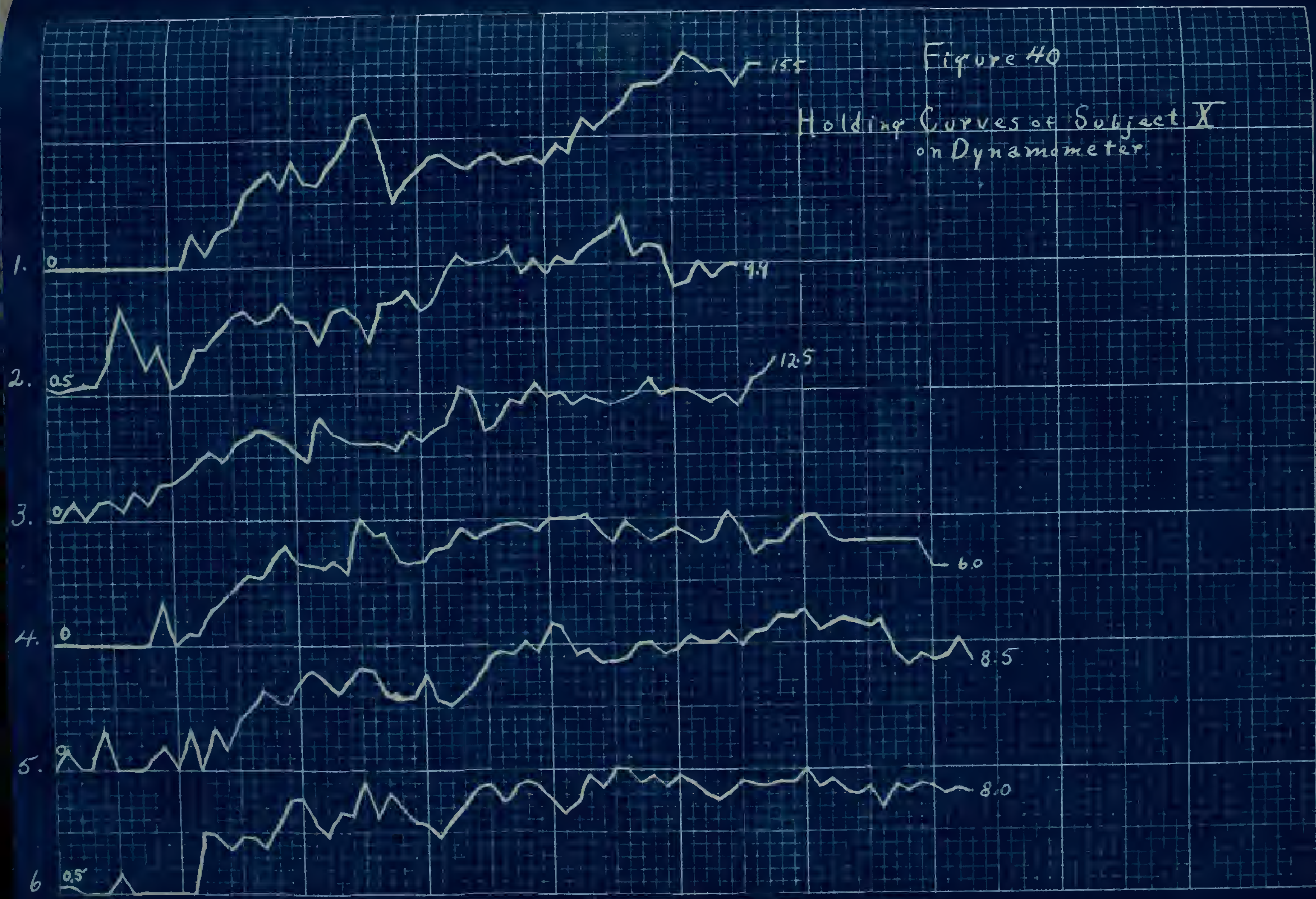



Figure 39

A Comparison of the Average Work Curve of Subject X as Taken in 1914 and in 1937

Figure 40

Holding Curves of Subject X on Dynamometer



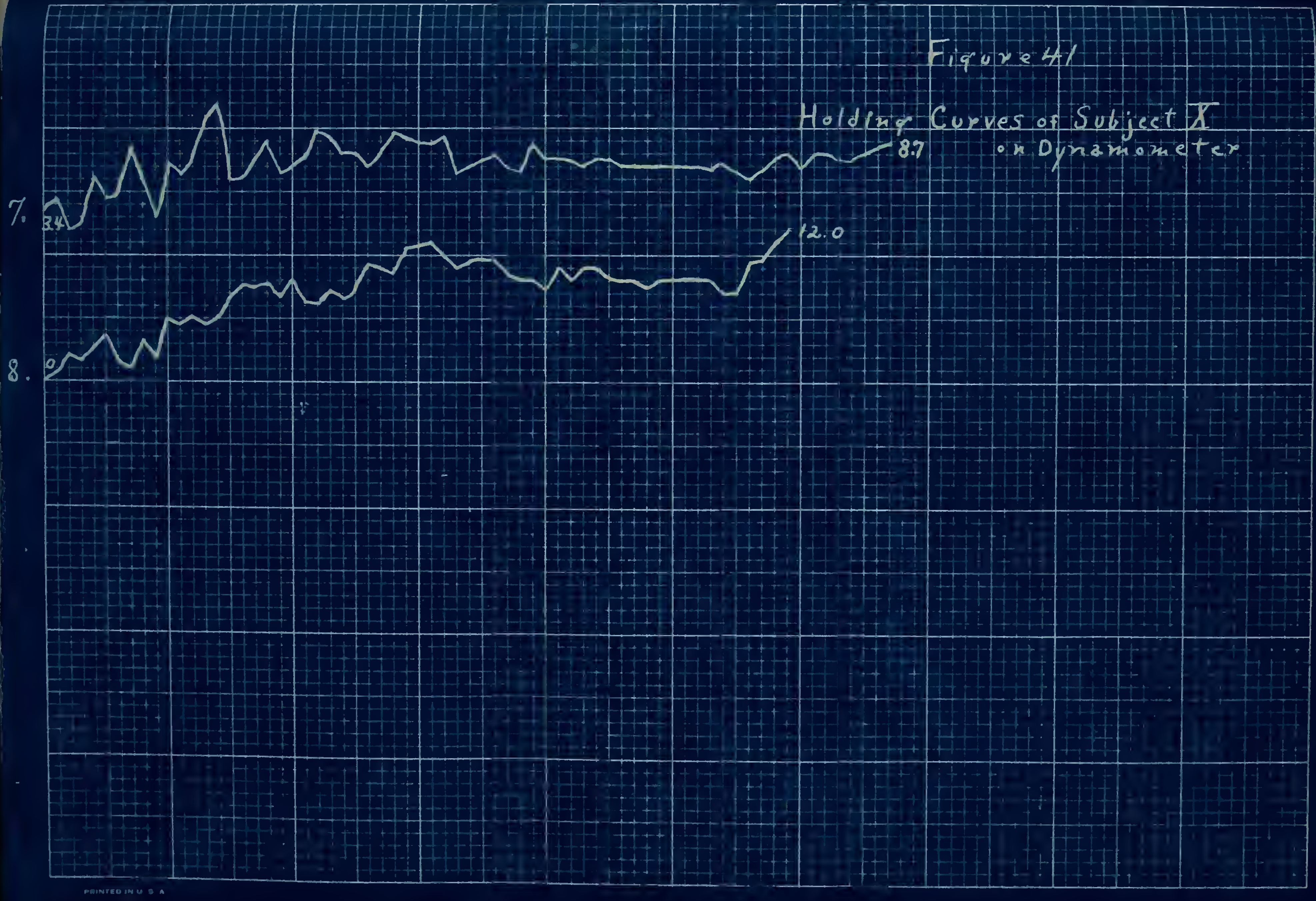



Figure 41

Holding Curves of Subject X on Dynamometer

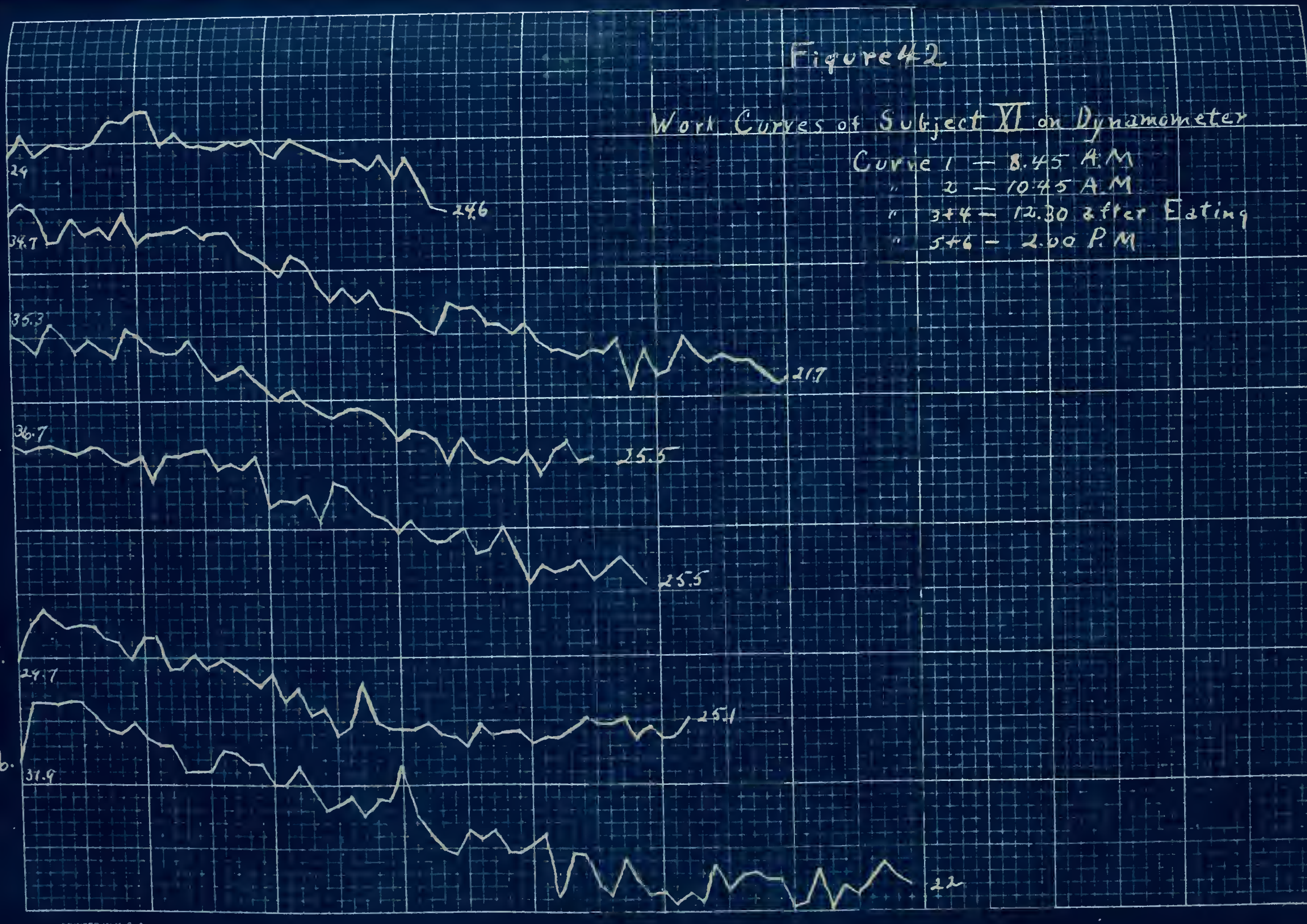


Figure 42
Work Curves of Subject XI on Dynamometer
Curve 1 — 8.45 A.M
" 2 — 10.45 A.M
" 3+4 — 12.30 after Eating
" 5+6 — 2.00 P.M
1.
24
24.6
2.
34.7
35.3
3.
21.7
36.7
4.
25.5
25.5
5.
24.7
25.1
6.
31.9
22
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Figure 43

Work Curves of Subject XI on Dynamometer
2.00 P.M.

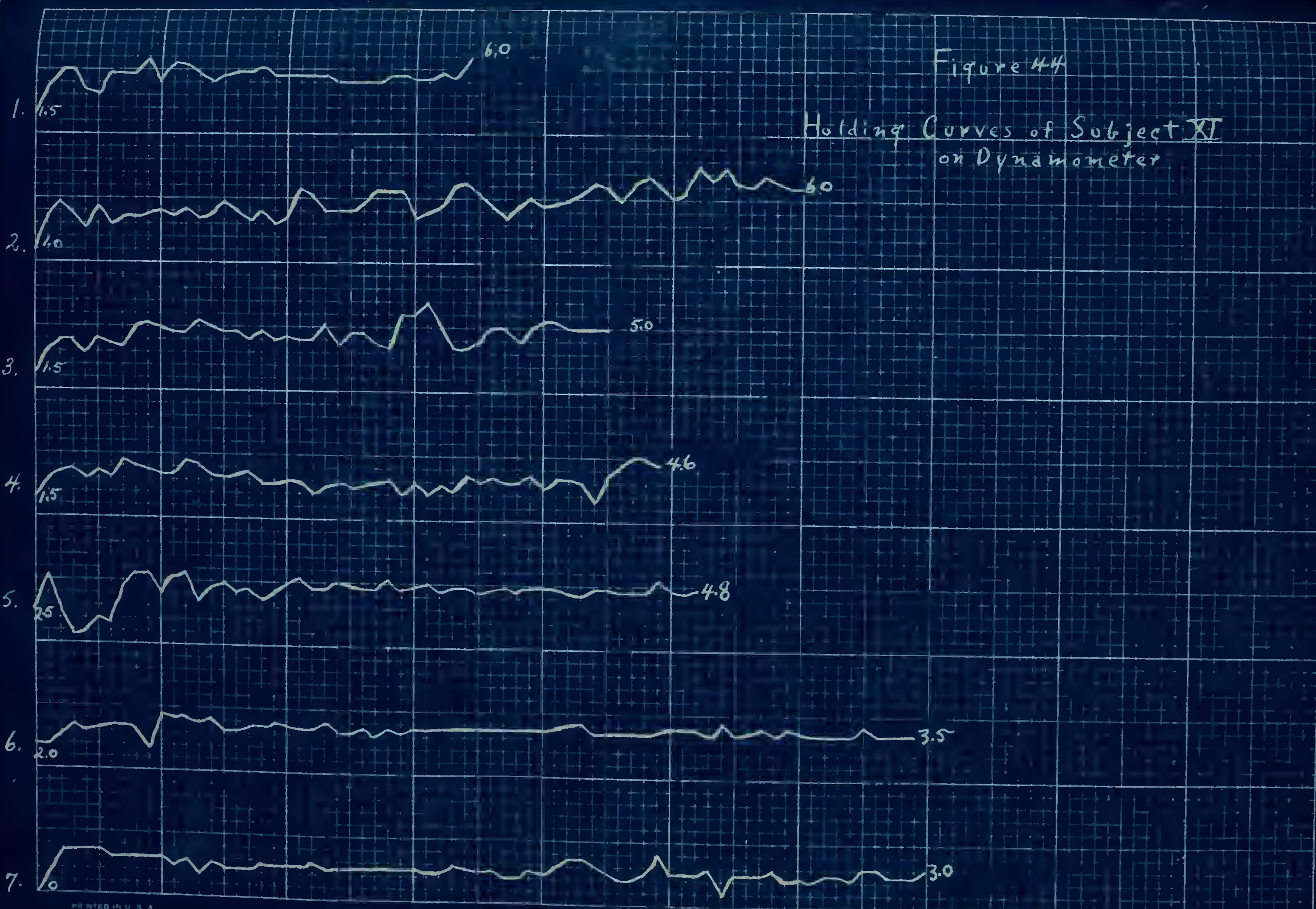
Figure 44
Holding Curves of Subject XI
on Dynamometer
1. 1.5 6.0
2. 1.0 6.0
3. 1.5 5.0
4. 1.5 4.6
5. 2.5 4.8
6. 2.0 3.5
7. 0 3.0
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Figure 45

Holding Curves of Subject XI on Dynamometer

Figure 46

Work Curves of Subject XII on Dynamometer

Curves 1+2 — 10.00 A.M.

Curves 3+4 — 1.00 after Eating


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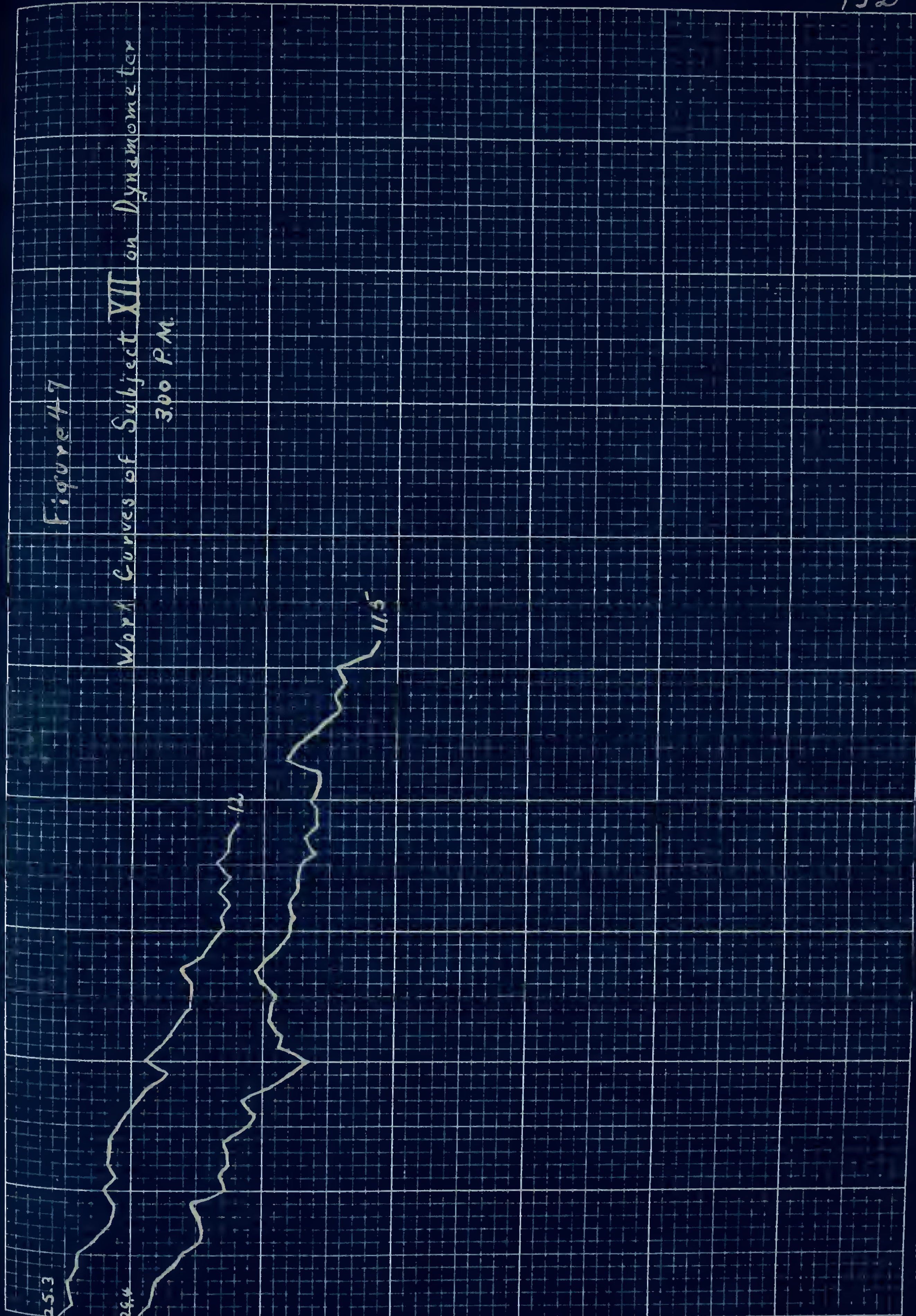
Figure 47
Work Curves of Subject XII on Dynamometer
3:00 P.M.
5.
6
25.3
24.4
12
11.5

Figure 48

Holding Curves of Subject XII on Dynamometer


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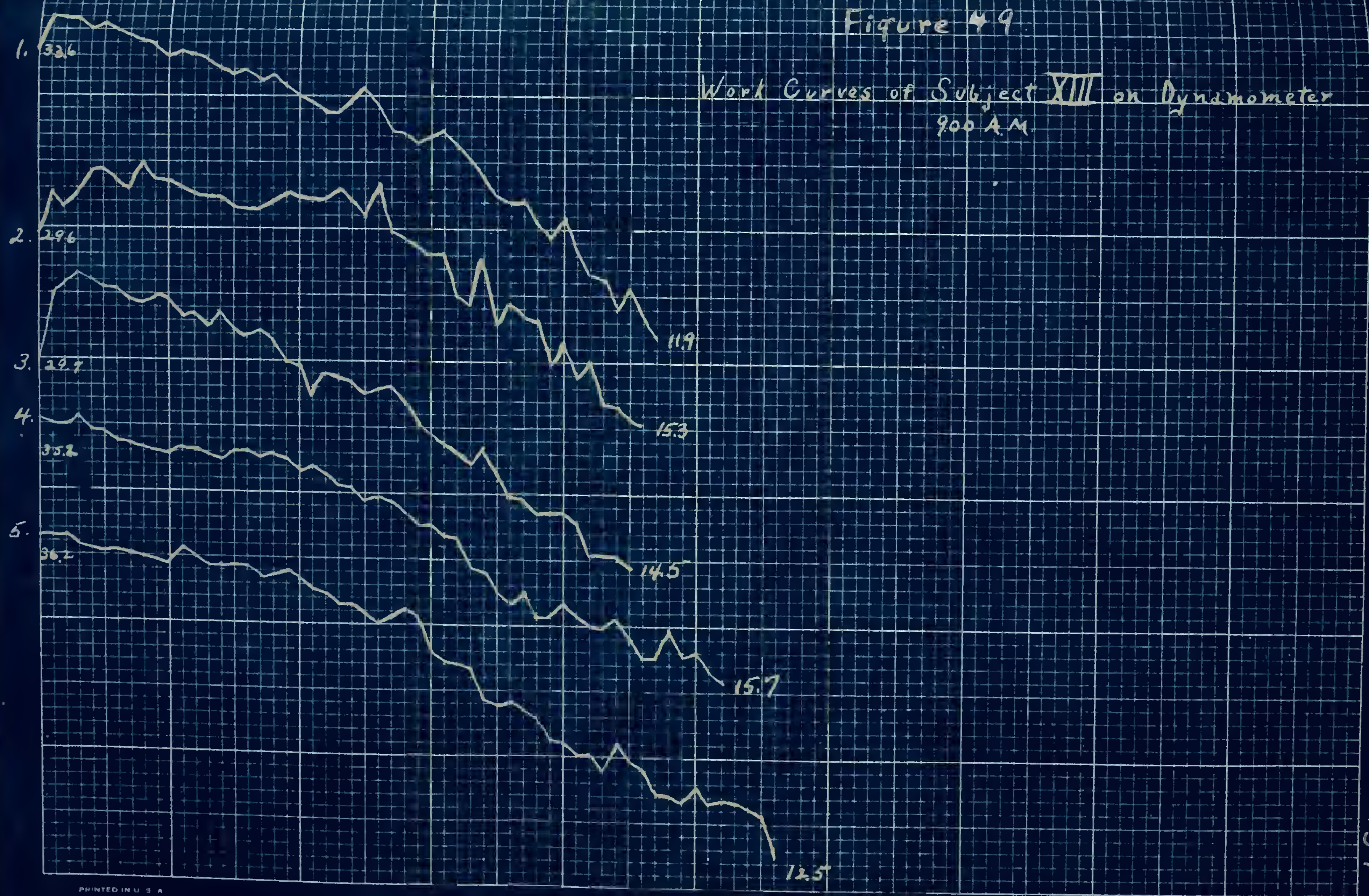
Figure 49

Work Curves of Subject XIII on Dynamometer
9.00 A.M.

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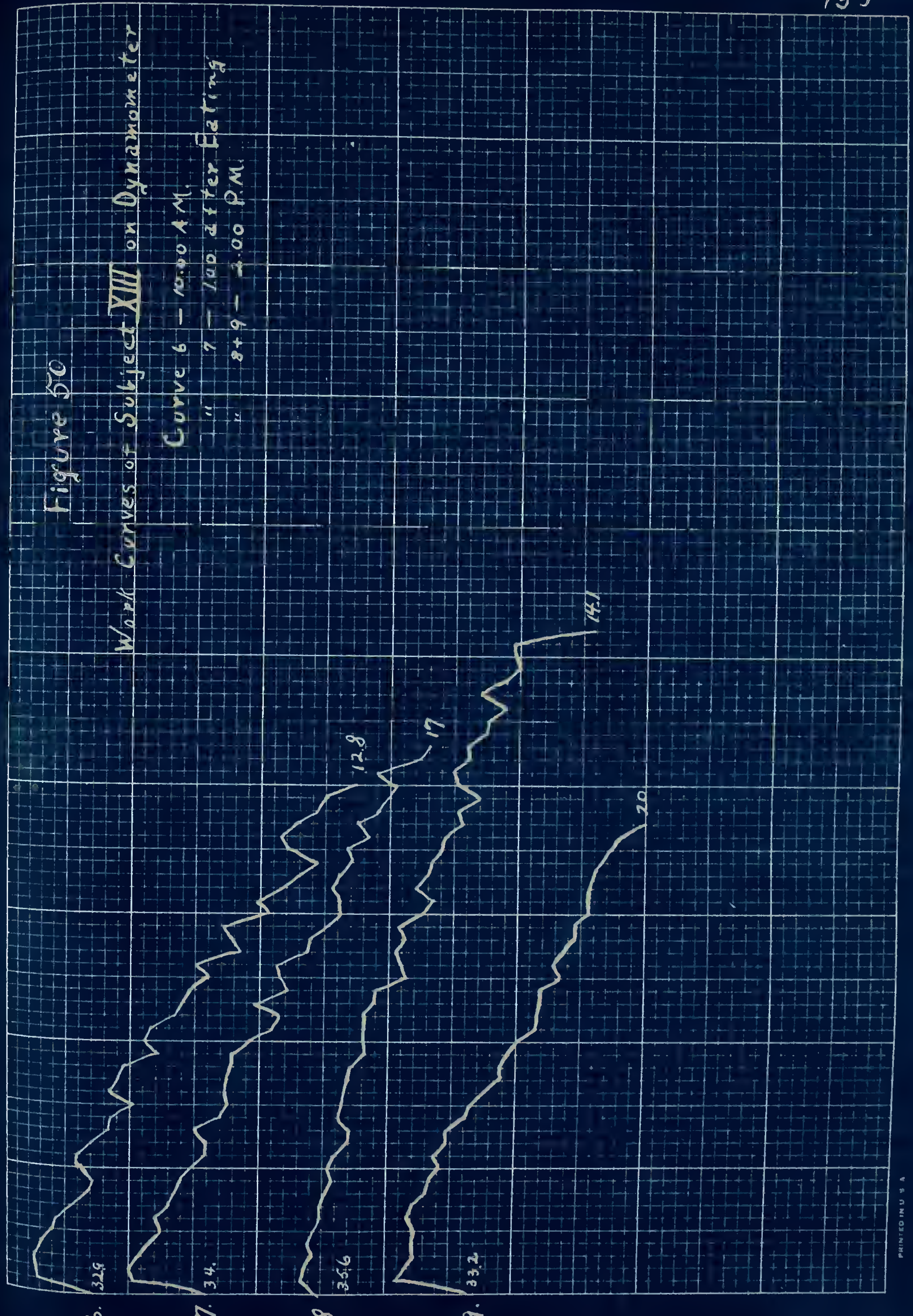
Figure 50
Work Curves of Subject XIII on Dynamometer
Curve 6 — 10.00 A.M.
" 7 — 1.00 after Eating
" 8+9 — 3.00 P.M.
6.
7.
8
9.
32.9
34.
35.6
33.2
12.8
17
14.1
20
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Figure 51

Holding Curves of Subject XIII on Dynamometer

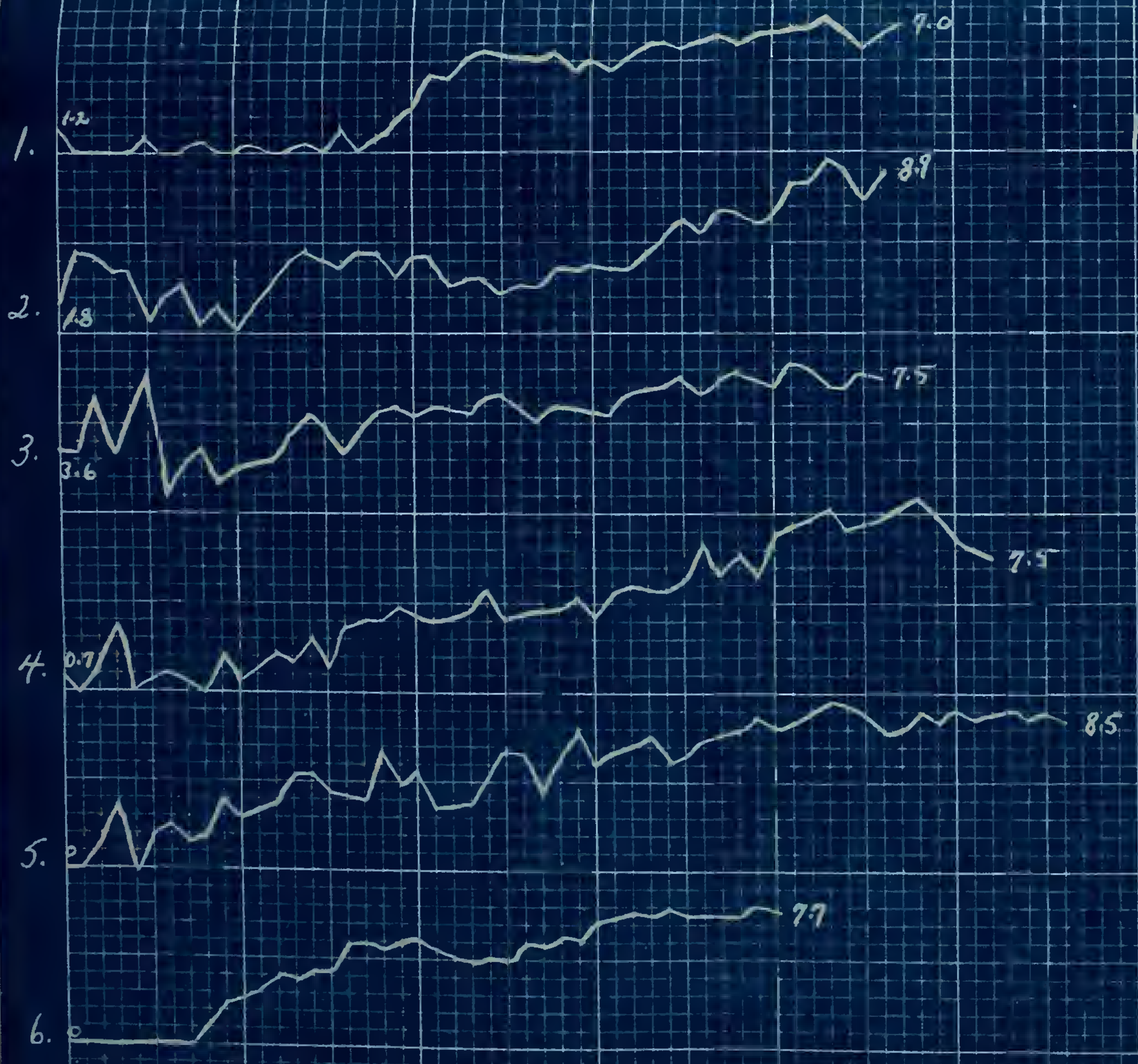


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Figure 52

Holding Curves of Subject XIII on Dynamometer

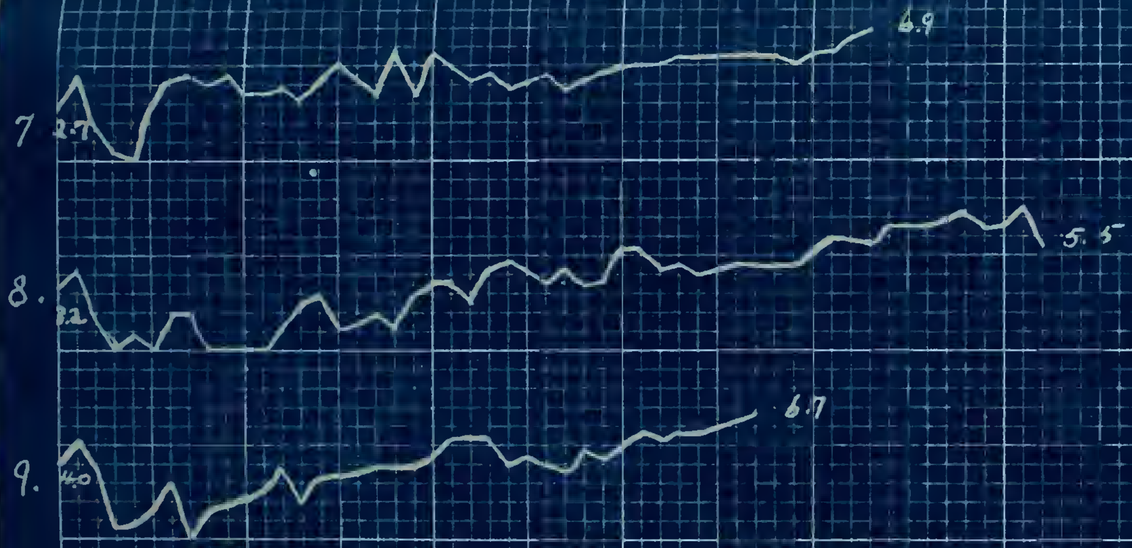


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Figure 53
Work Curve of Subject XIV on Dynamometer
Curves 1+2 — 10.00 A.M.
" 3+4 — 1.00 after Eating
" 5+6 — 3.00 P.M.
1. 35.3
2. 38.8
3. 33.4
4. 40.5
5. 30.9
6. 32.5
16.7
21.8
19.9
19.4
19.5
18.8
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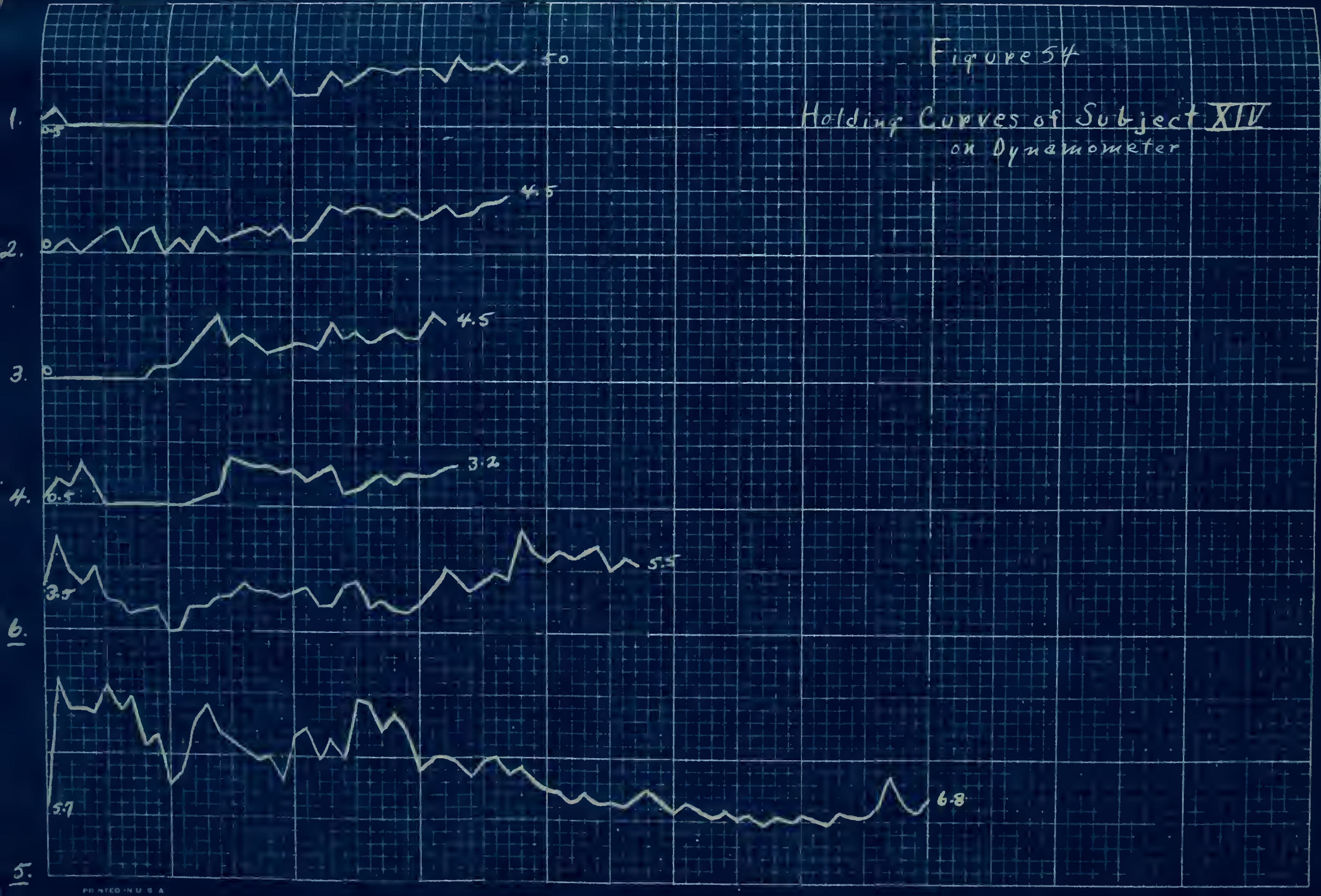
Figure 54
Holding Curves of Subject XIV
on Dynamometer
1.
2.
3.
4.
6.
5.
5.0
4.5
4.5
3.2
5.5
3.5
5.7
6.8
0
0

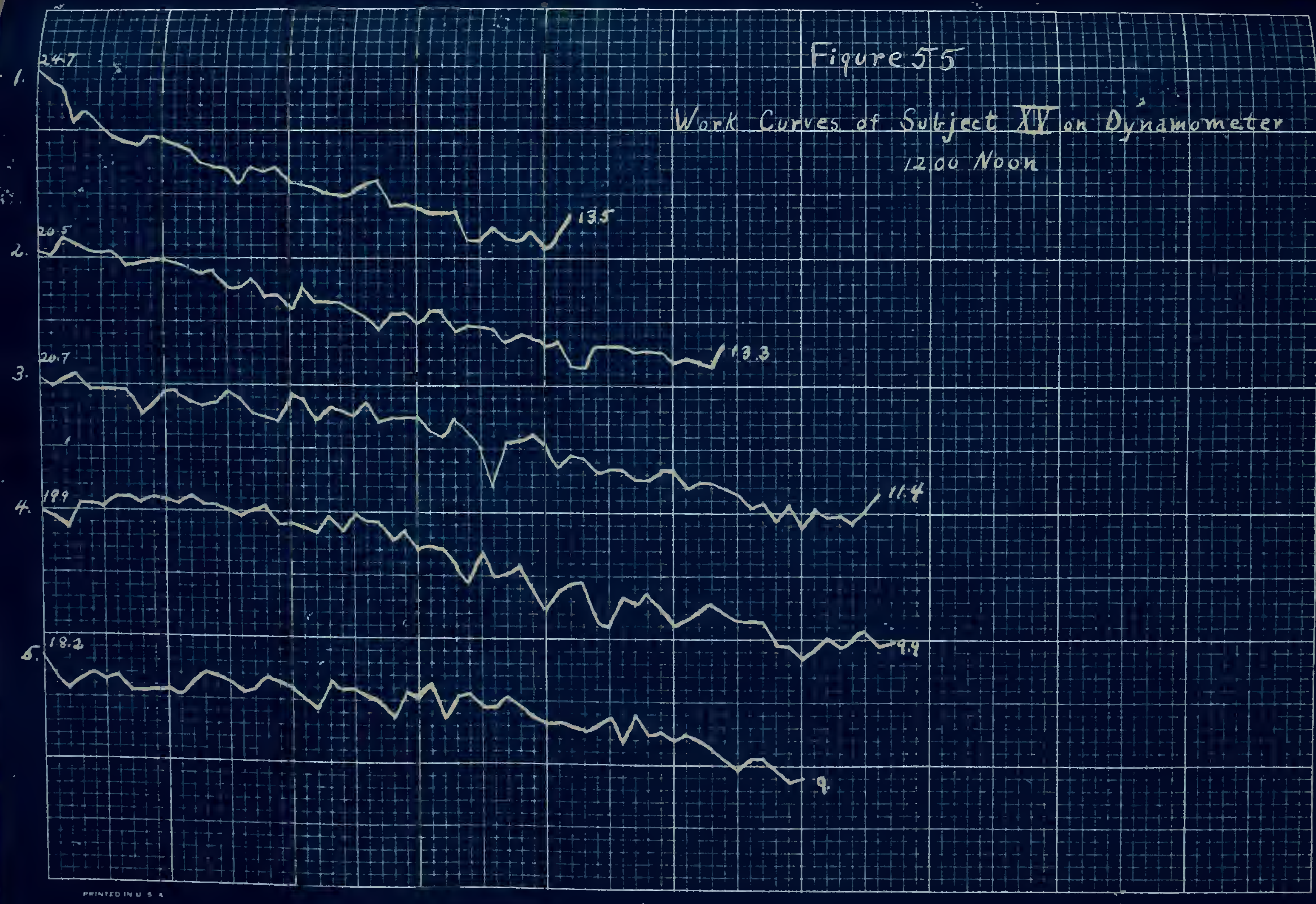
Figure 55
Work Curves of Subject XIV on Dynamometer
12.00 Noon
1.
24.7
13.5
2.
20.5
13.3
3.
20.7
11.4
4.
19.9
9.9
5.
18.2
9
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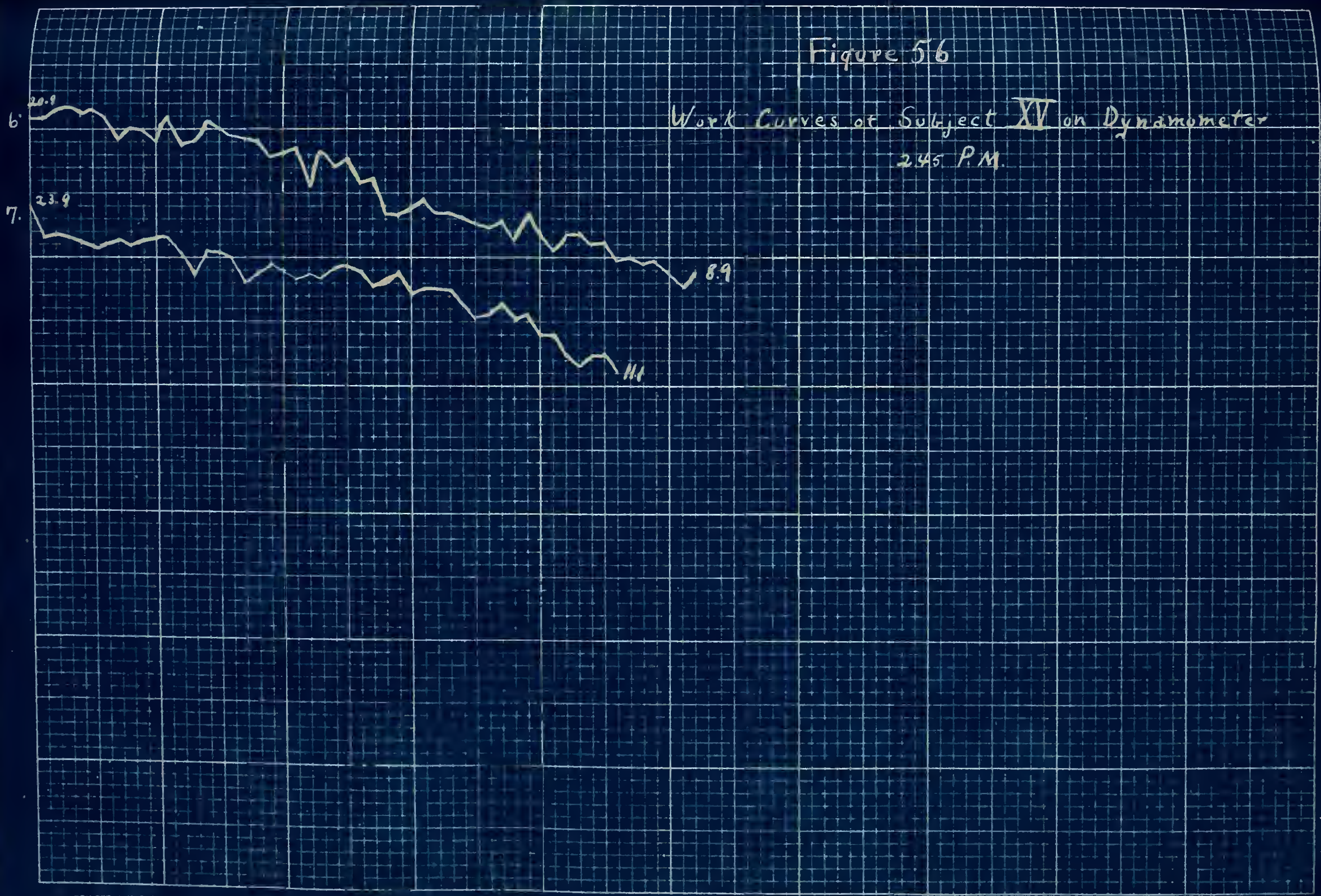
Figure 56

Work Curves of Subject XV on Dynamometer

2.45 P.M.



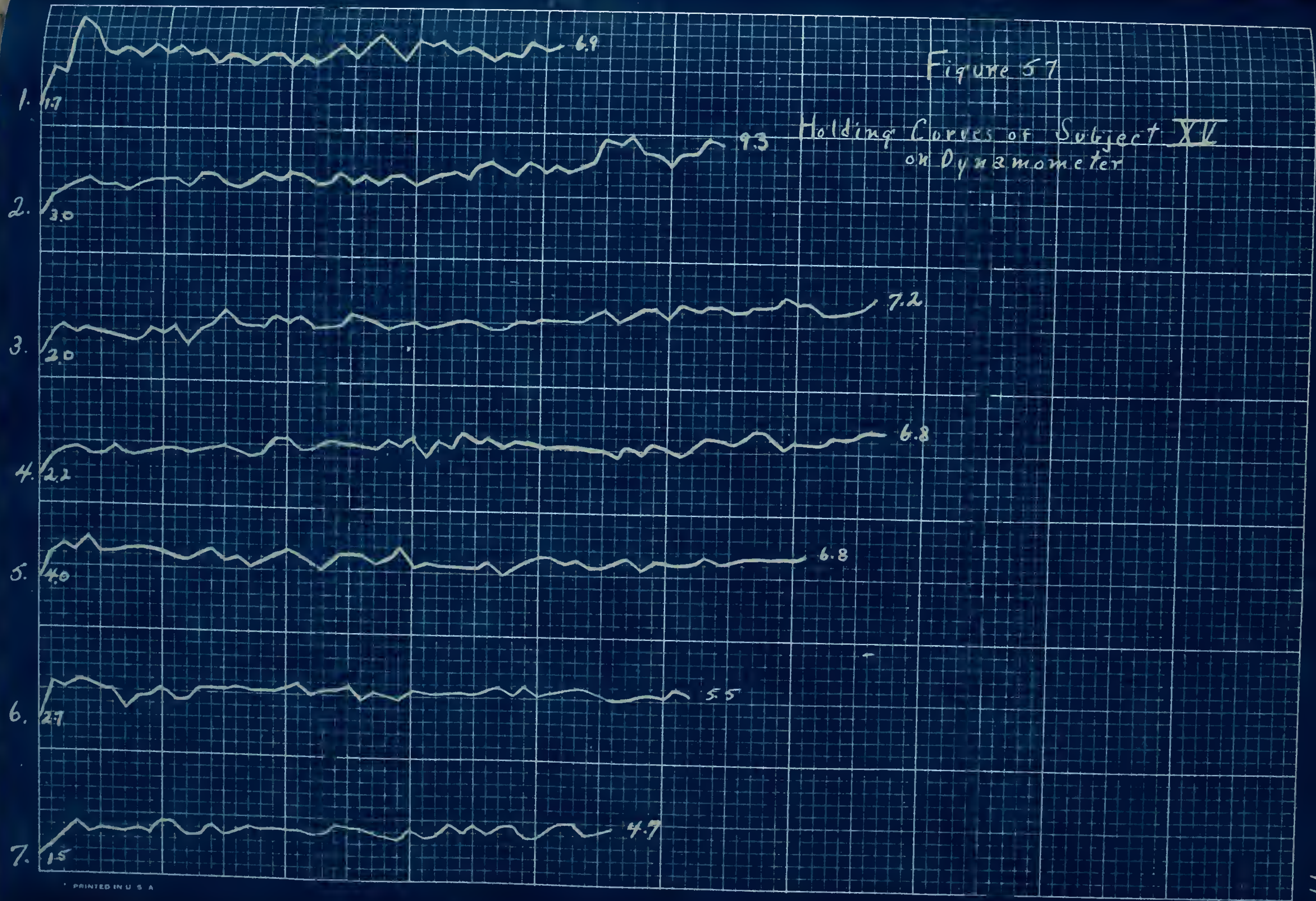


Figure 57
Holding Curves of Subject XII
on Dynamometer
1. 1.7
6.9
2. 3.0
9.3
3. 2.0
7.2
4. 2.2
6.8
5. 4.0
6.8
6. 2.7
5.5
7. 1.5
4.7
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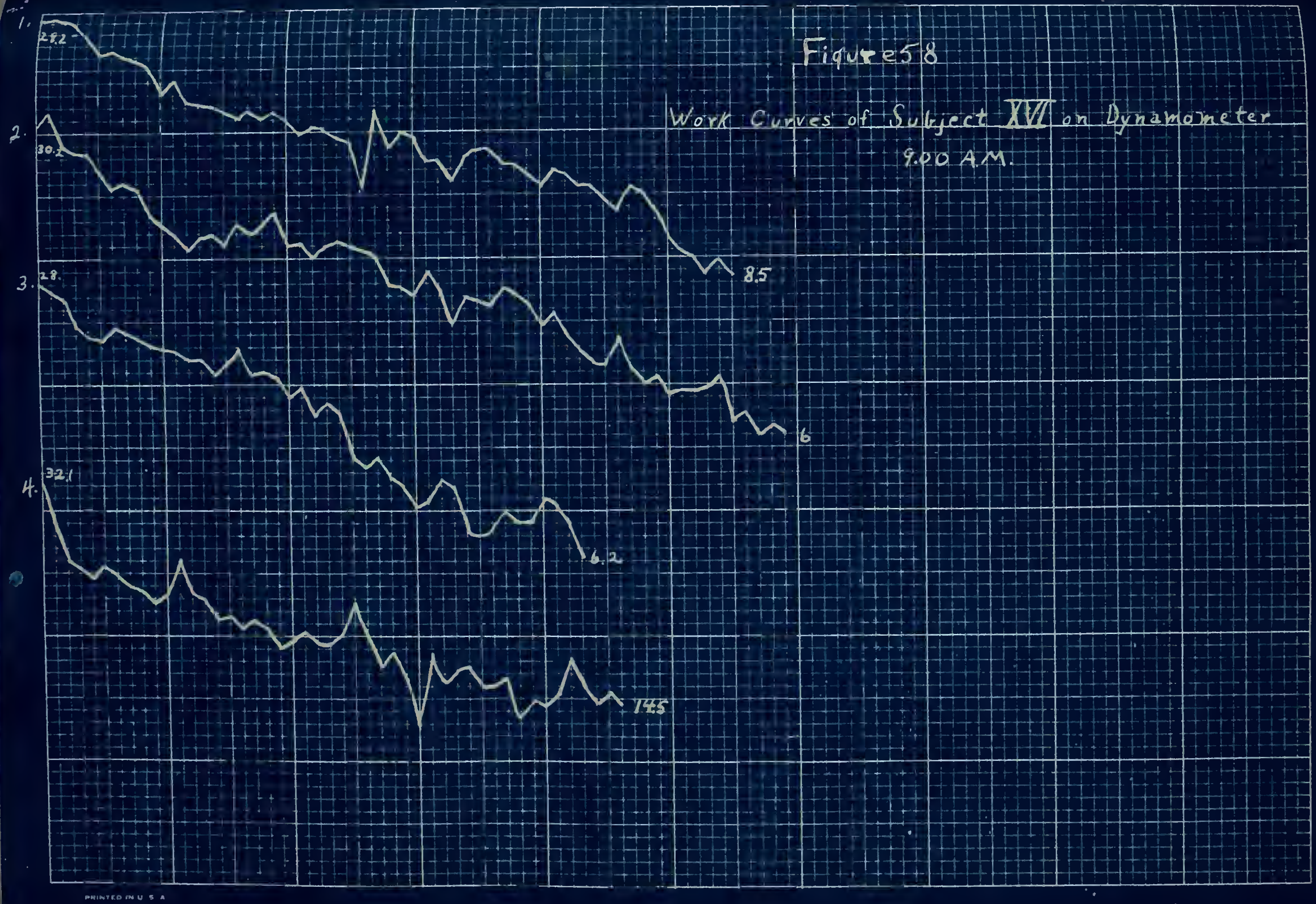



Figure 58

Work Curves of Subject XVI on Dynamometer

9.00 A.M.

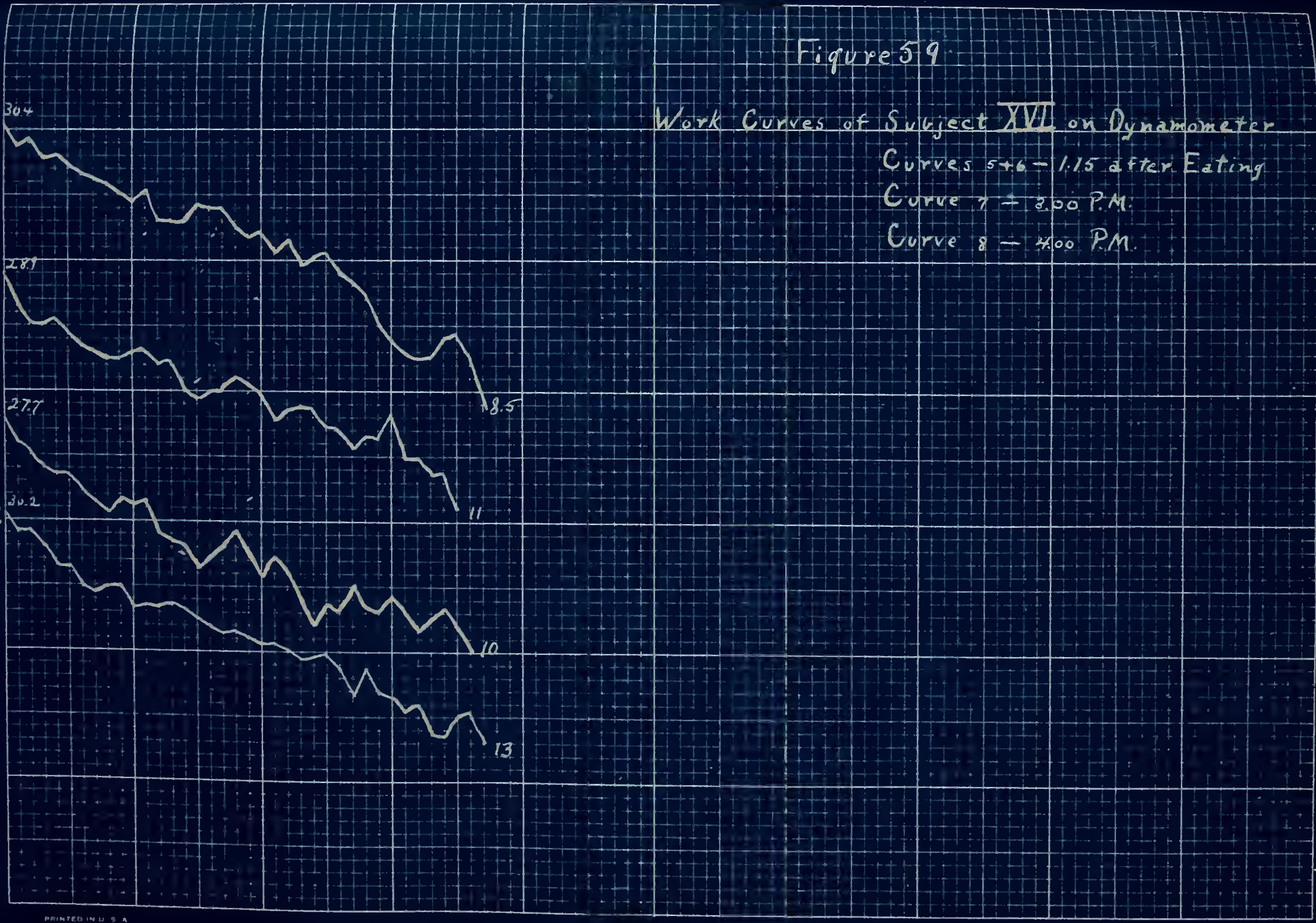



Figure 59

Work Curves of Subject XVI on Dynamometer

Curves 5+6 — 1.15 after Eating

Curve 7 — 3.00 P.M.

Curve 8 — 4.00 P.M.

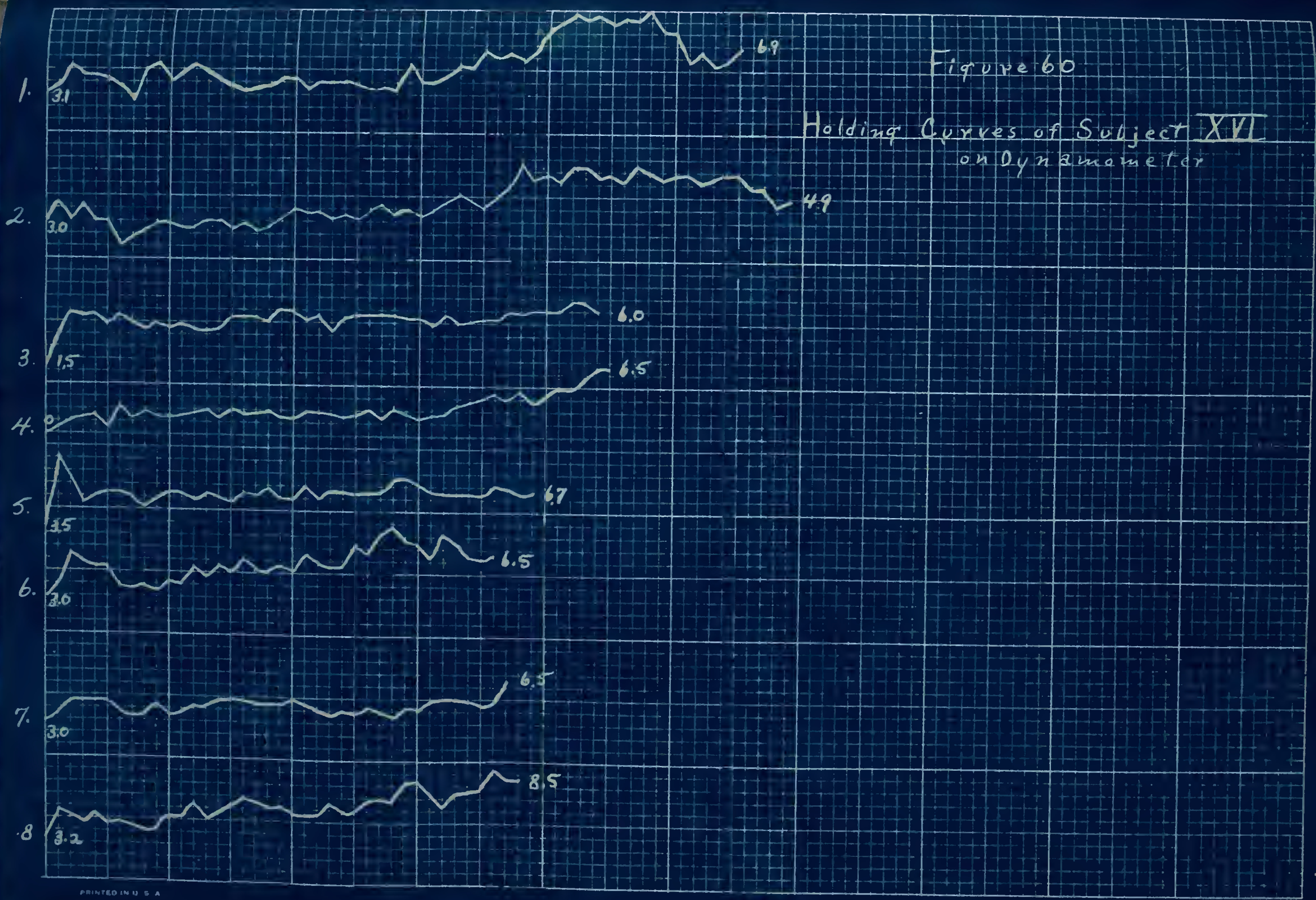


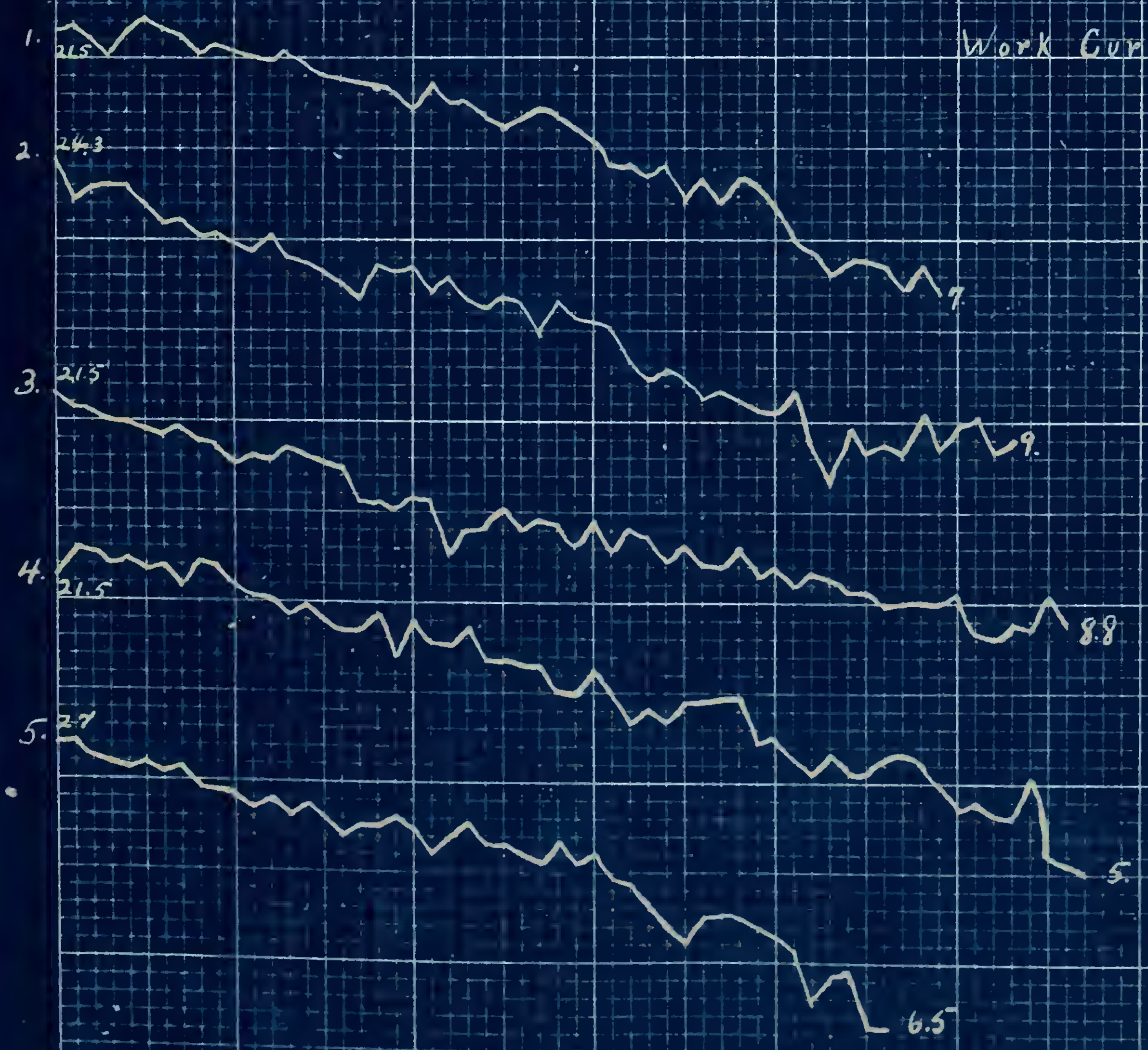

Figure 60

Holding Curves of Subject XVI
on Dynamometer

Figure 61

Work Curves of Subject XVII on Dynamometer

9.40 A.M.



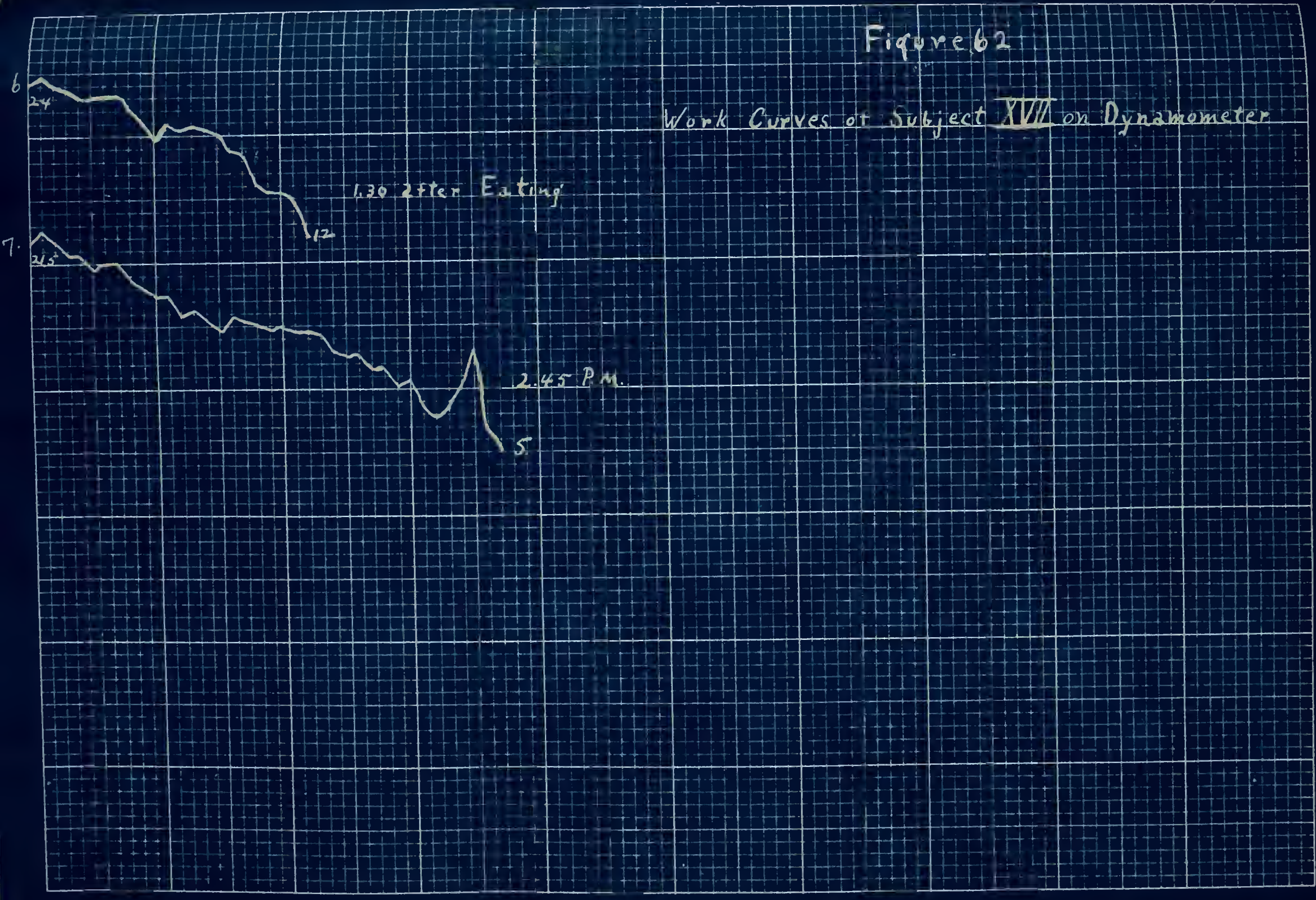



Figure 62

Work Curves of Subject XVII on Dynamometer

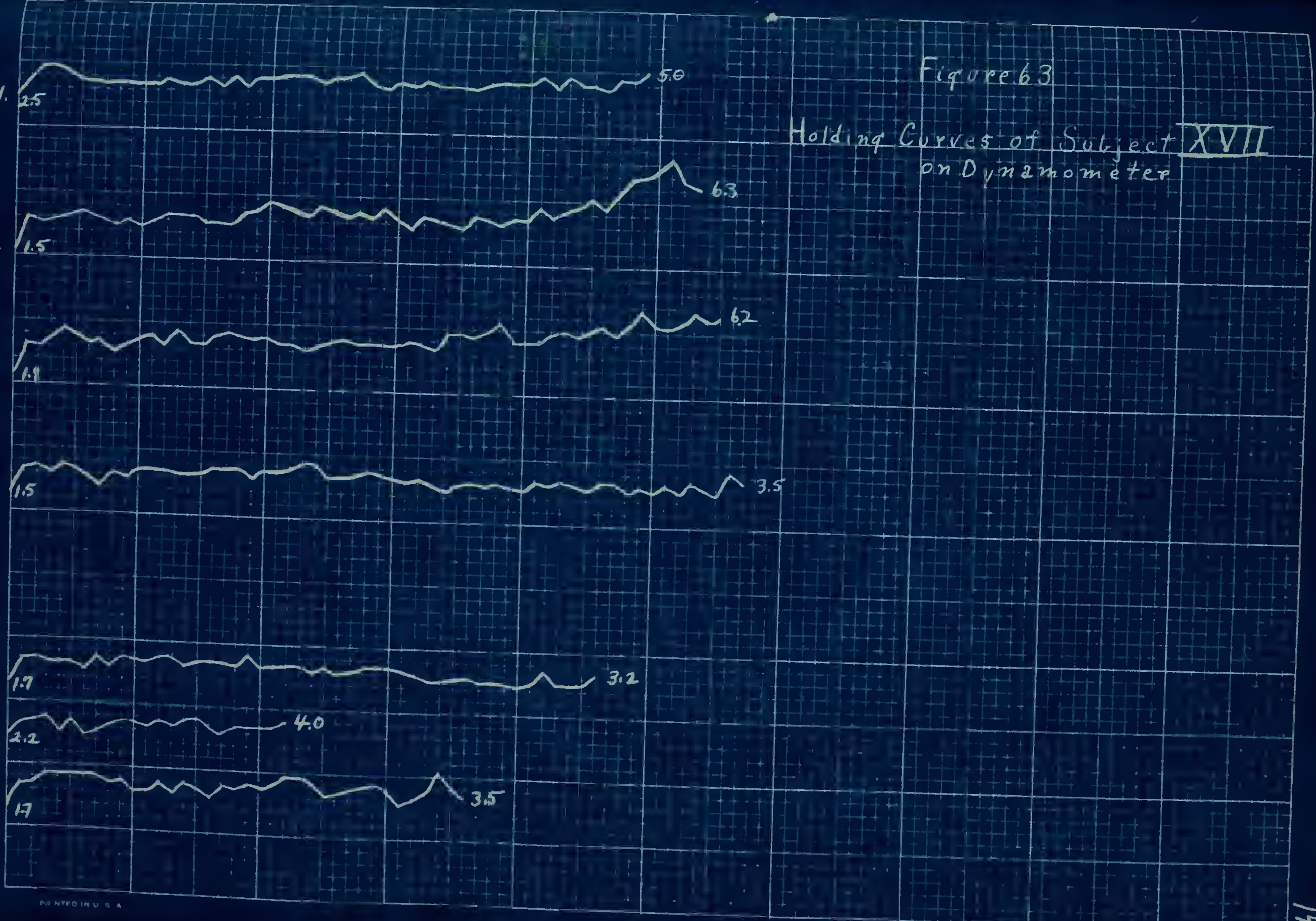



Figure 63

Holding Curves of Subject XVII on Dynamometer

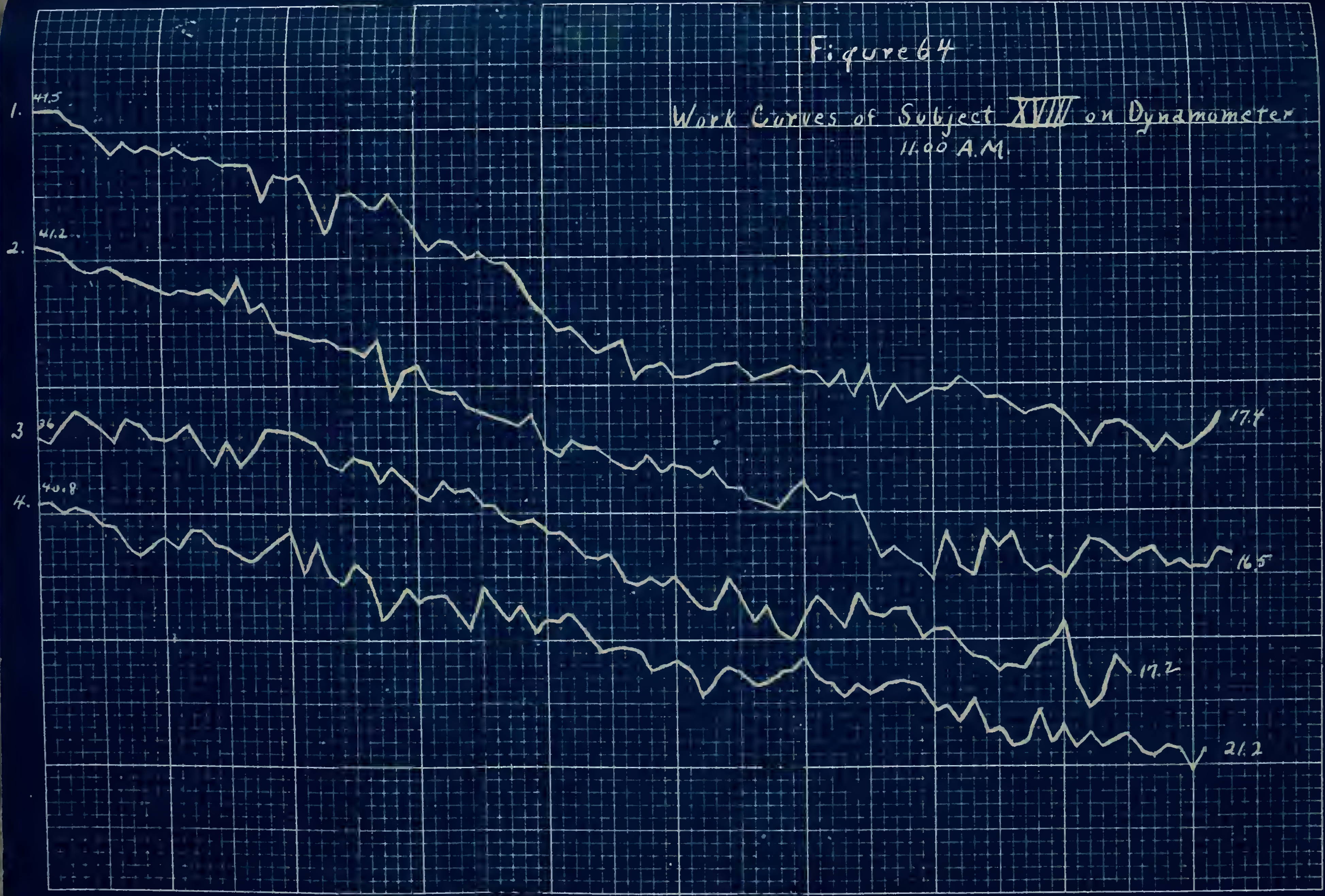



Figure 64

Work Curves of Subject XVIII on Dynamometer
11.00 A.M.

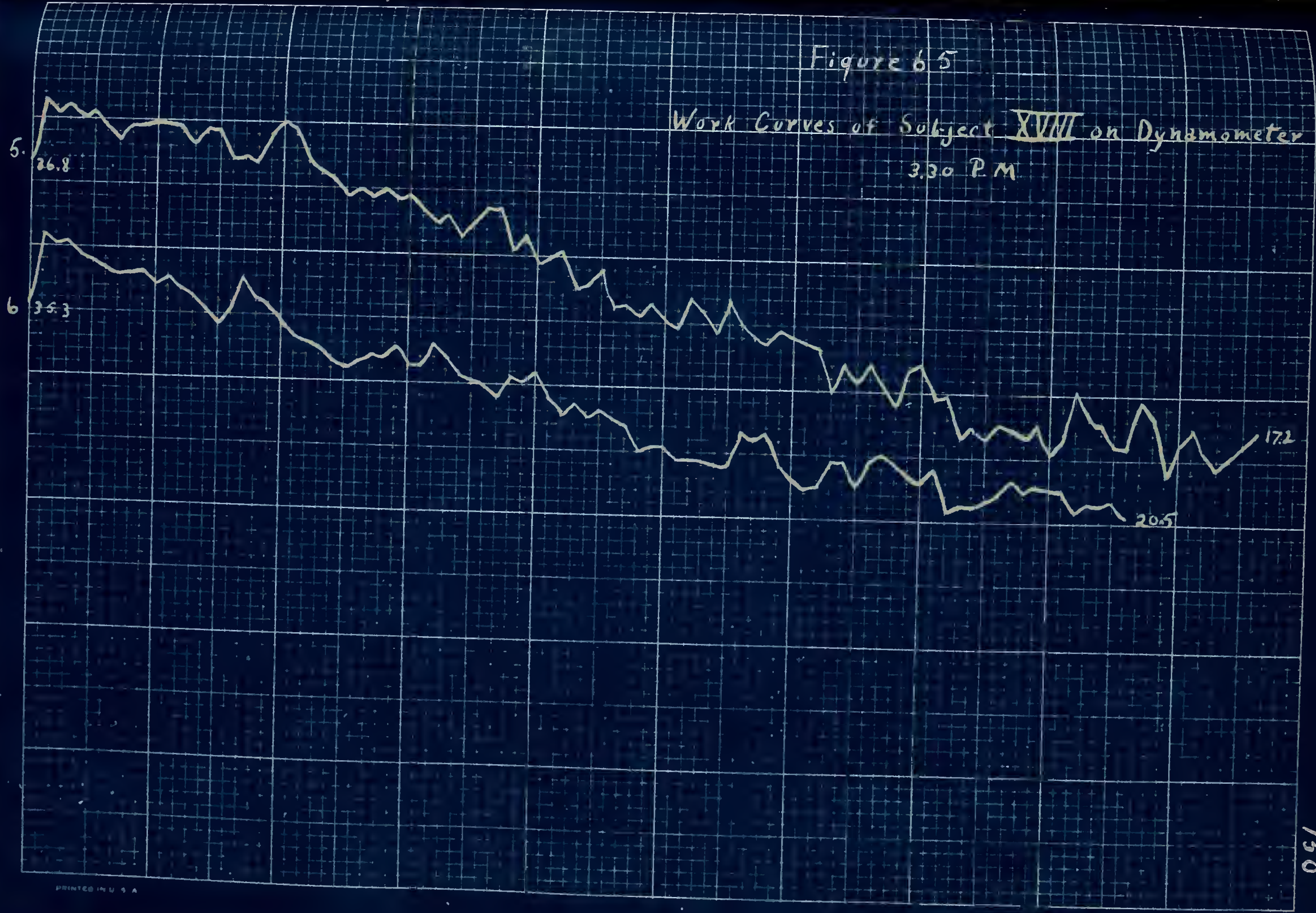


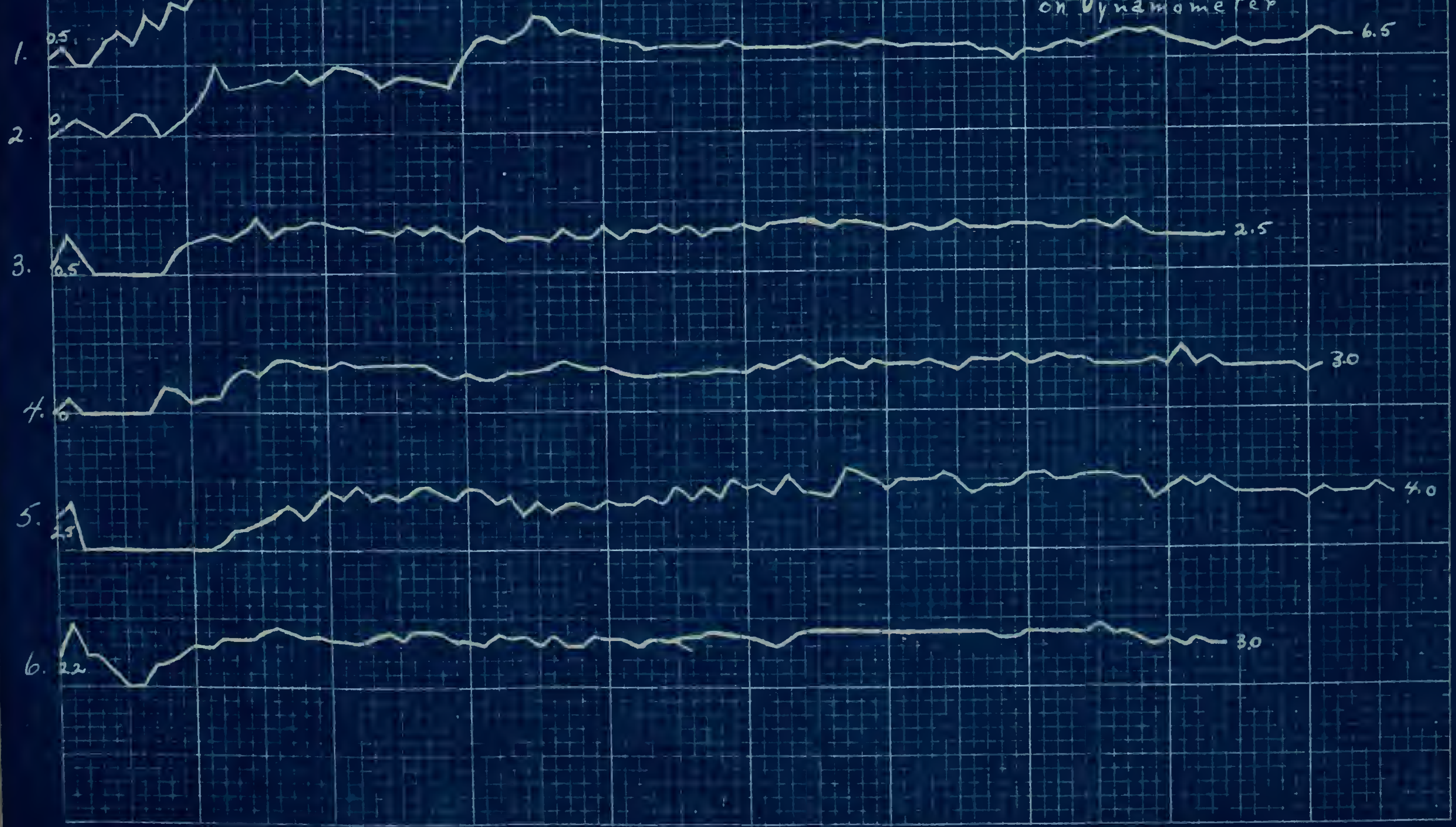

Figure 65

Work Curves of Subject XVIII on Dynamometer

3.30 P. M

Figure 66

Holding Curves of Subject XVIII
on Dynamometer



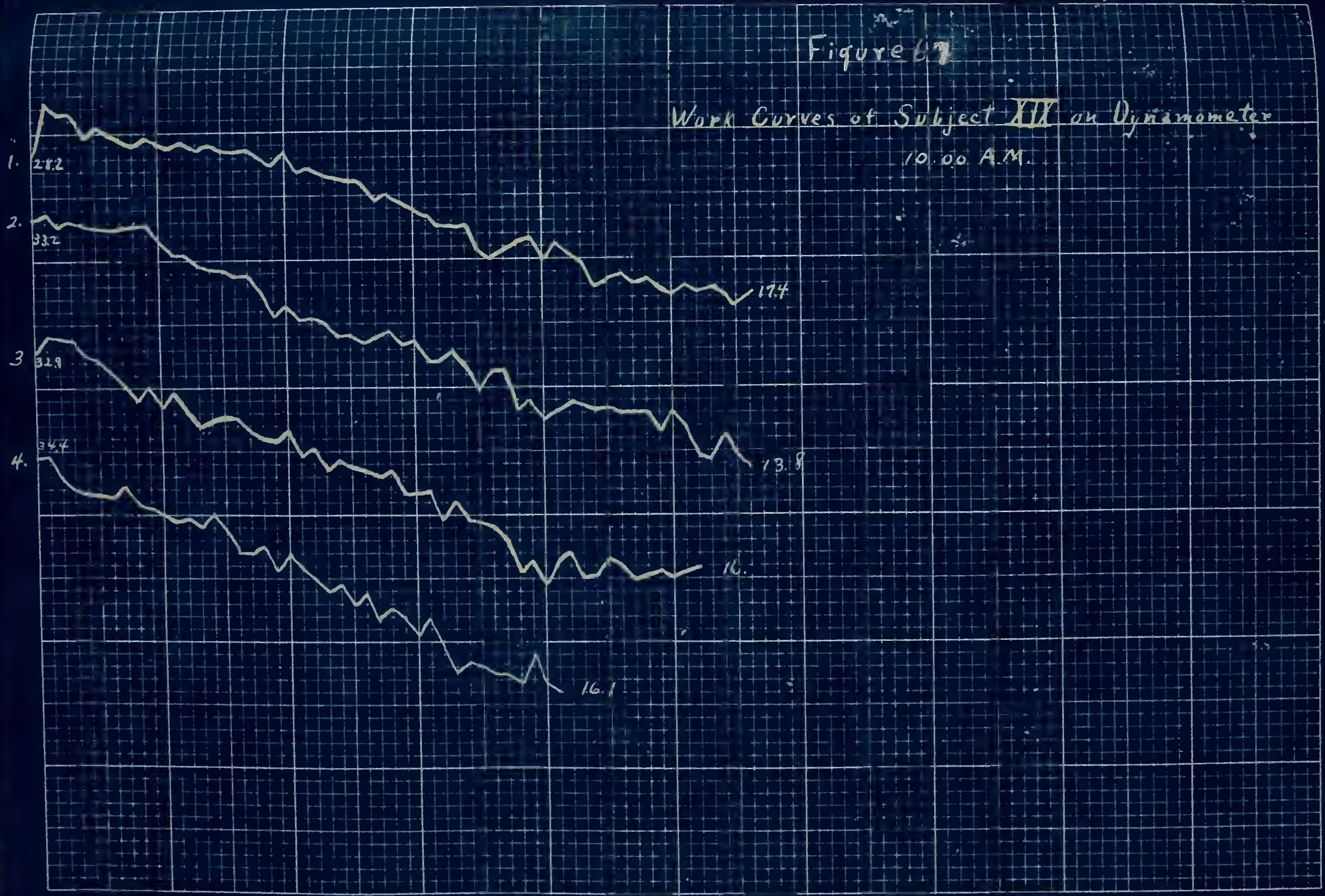



Figure 67

Work Curves of Subject XII on Dynamometer

10.00 A.M.

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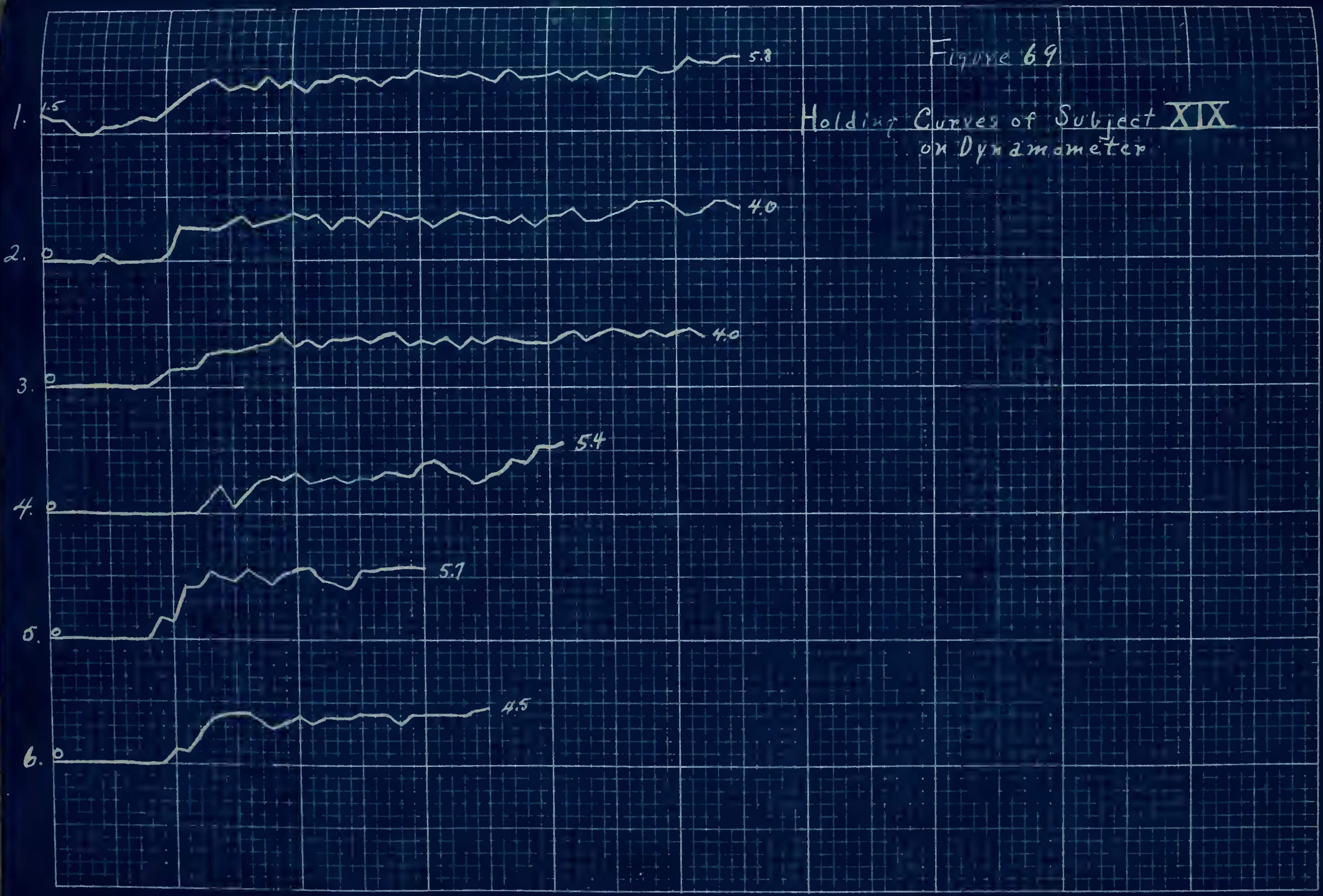
Figure 68

Work Curves of Subject XIX on Dynamometer

3.00 P.M.

Figure 69

Holding Curves of Subject XIX on Dynamometer



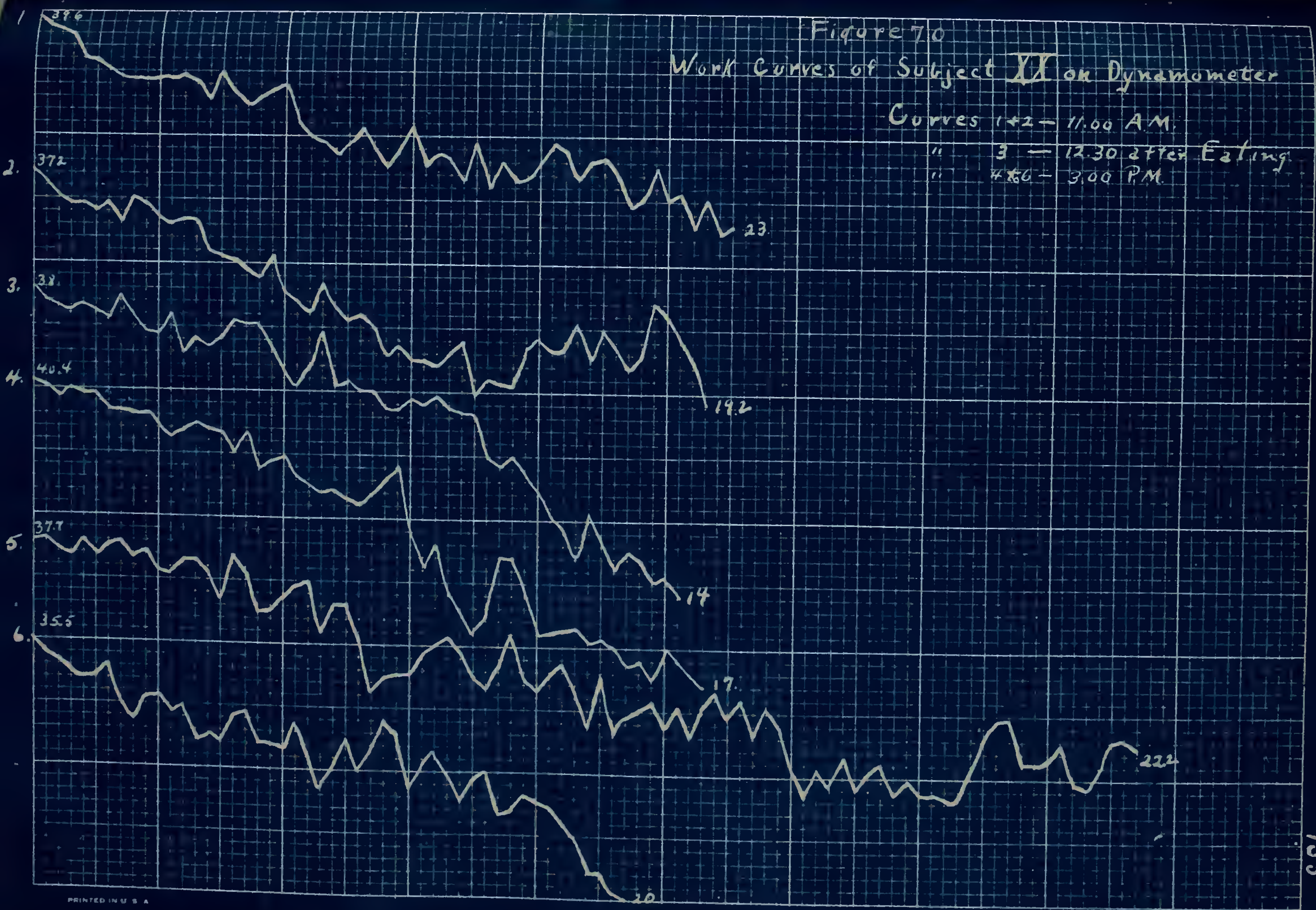


Figure 70
Work Curves of Subject XI on Dynamometer
Curves 1+2 – 11.00 AM.
" 3 – 12.30 after Eating
" 4+6 – 3.00 P.M.
1
39.6
23
2.
37.2
19.2
3.
38.
4.
40.4
14
5.
37.7
17.
6.
35.5
22.2
20
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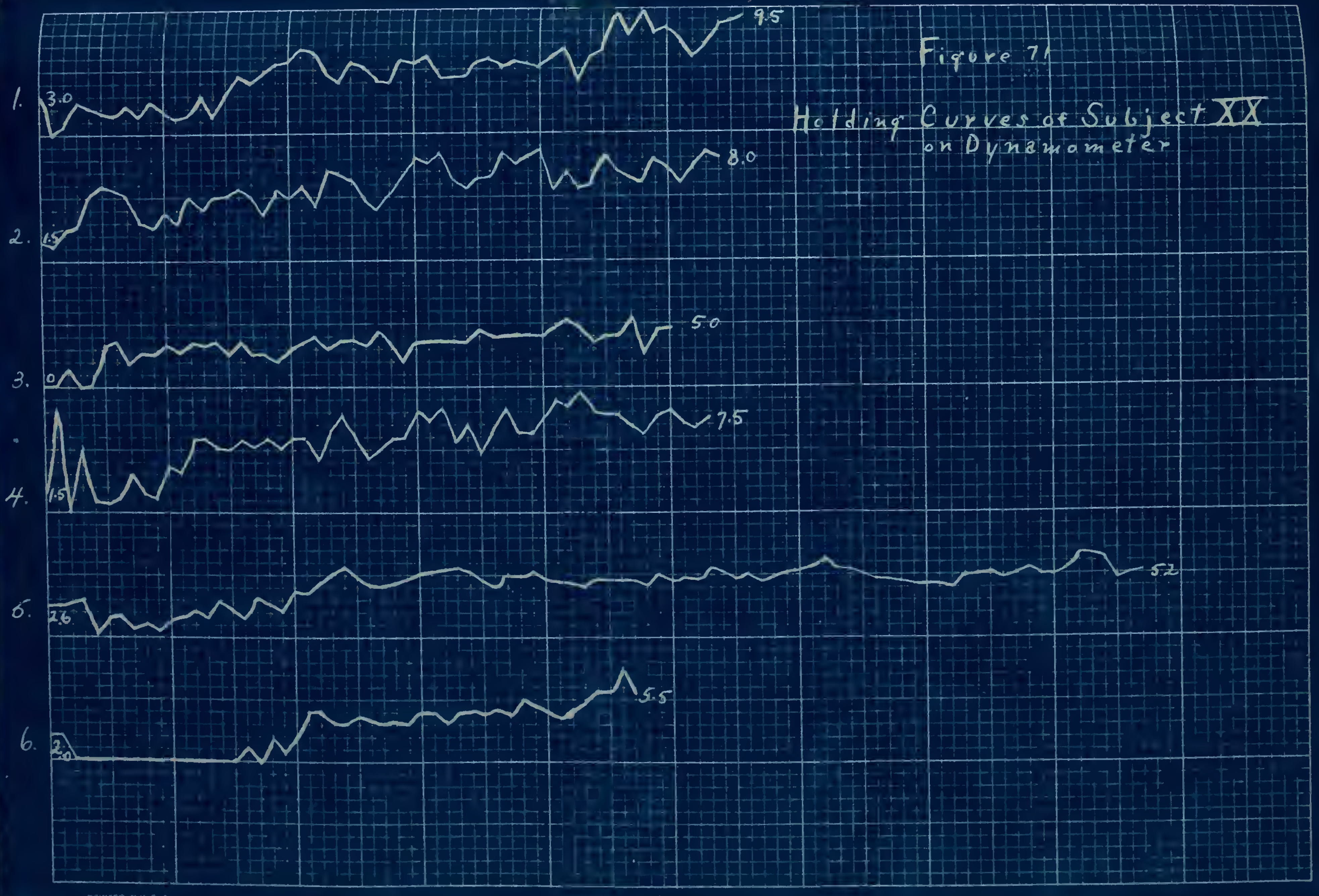

Figure 71
Holding Curves of Subject XX on Dynamometer
1.
3.0
9.5
2.
1.5
8.0
3.
0
5.0
4.
1.5
7.5
6.
7.6
5.2
6.
2.0
5.5

Figure 72

Work Curves of Subject XXI on Dynamometer

Curve 1+2 — 9.45 A.M.
" 3+4 — 2.00 P.M.
" 5 — 4.00 P.M.


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Figure 73

Holding Curves of Subject XXI
on Dynamometer

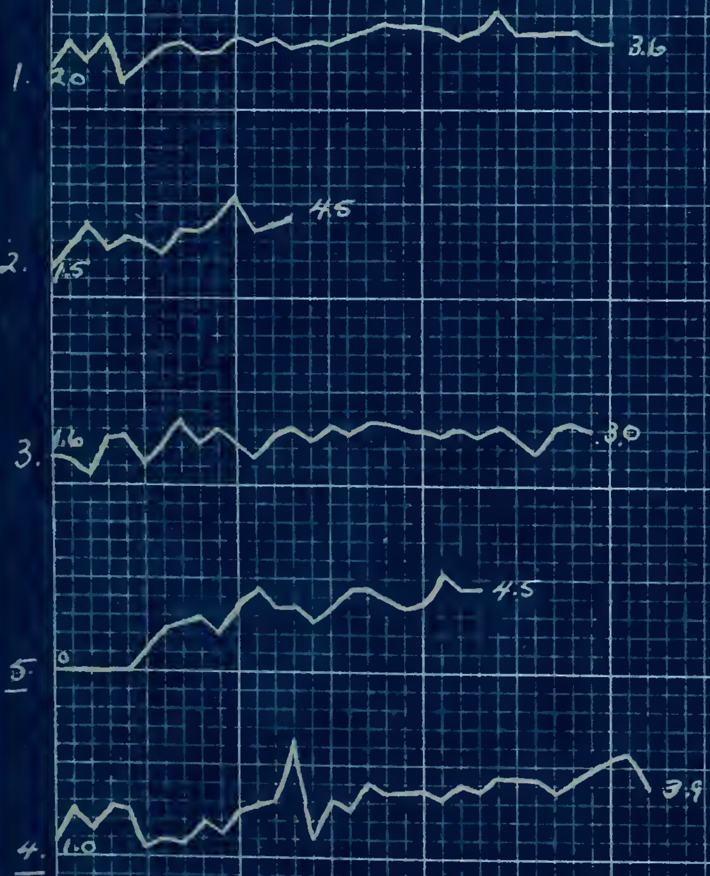


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Figure 74

Work Curves of Subject XXII on Dynamometer
10.00 A.M.

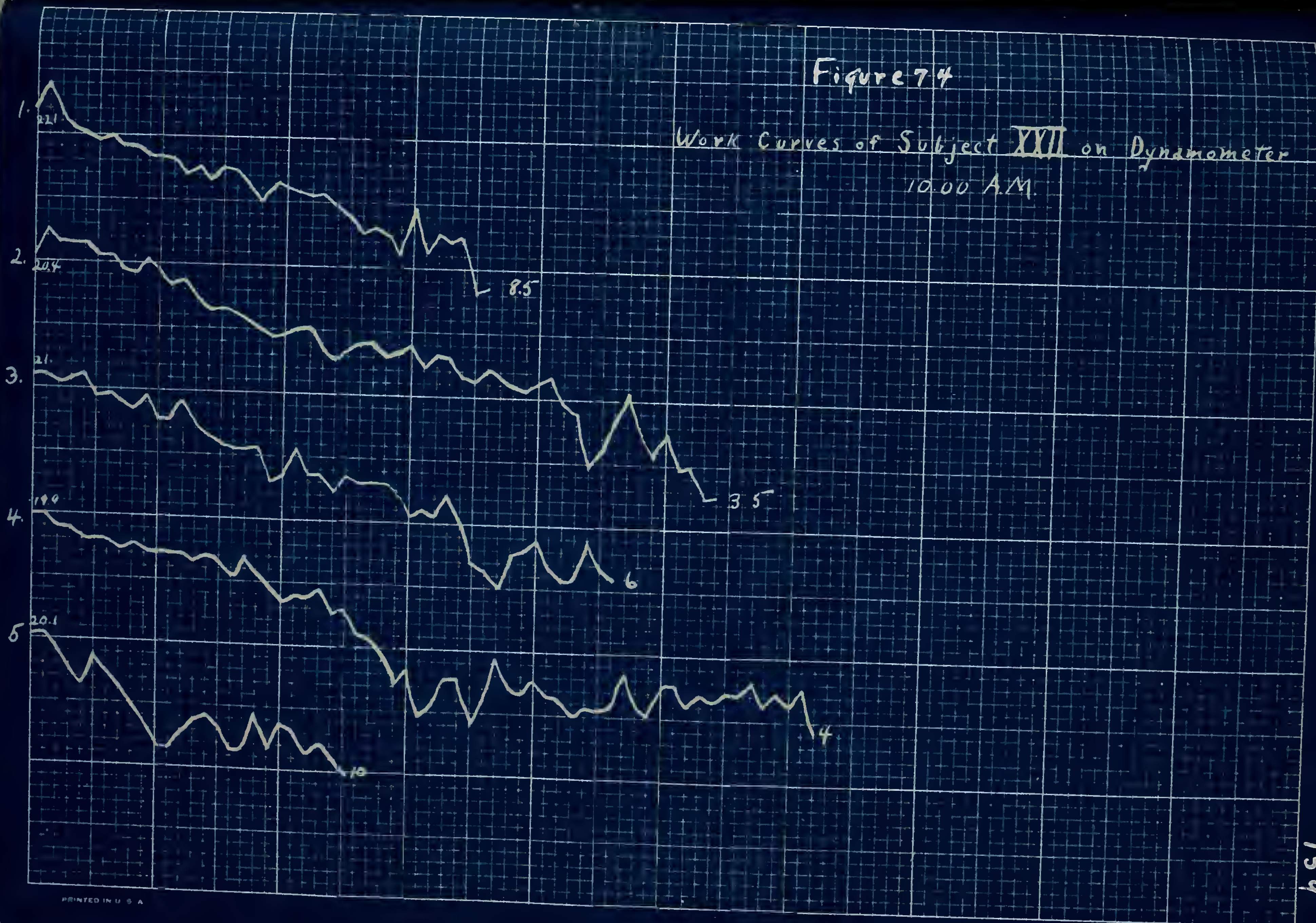

Figure 75

Work Curves of Subject XXII on Dynamometer

Curve 6 – 1.00 after Eating
" 7+8 – 2.00 P.M.


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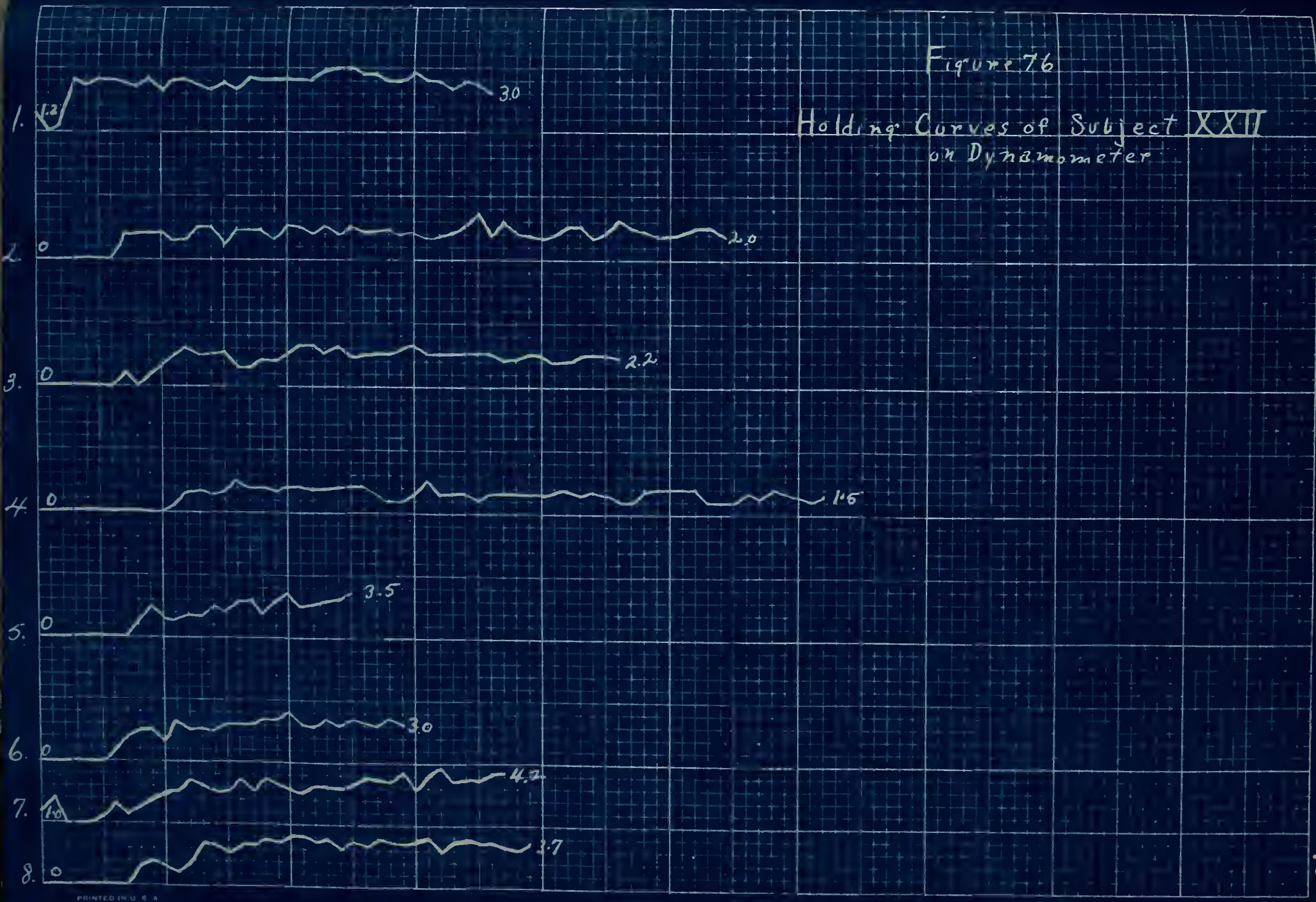



Figure 76

Holding Curves of Subject XXII on Dynamometer

## A. GENERAL DISCUSSION OF FATIGUE CURVES RESULTING FROM WORK UPON THE DYNAMOMETER.

The outstanding conclusion that can be drawn from even a cursory glance at the individual curves presented in Figures 1 to 76 is that there is no "typical" fatigue curve for work upon the dynamometer. There is stark variation between individuals. Witness, for example, the different trends in the curves of Subject I (fig. 1), Subject VIII (fig. 29) and Subject X (fig. 34). Subject I almost invariably begins with a short warming-up period followed by a rapid decline. Subject VIII begins in an irregular manner, and carries on at an almost steady level of performance with only gradual decline toward end. Subject X invariably exhibits his maximum contraction first, has an initial spurt followed by a plateau, and than begins a gradual descent. Take any other three individuals at random, and the variation among them will be equally as evident.

A second and more important point to be emphasized, is that, for the most part, each individual presents a curve from day to day that may be said to be <u>his</u> personal curve alone. There are exceptions to this statement, of course. The daily variation between the curves of the last three subjects (XX, XXI, and XXII) is oftentimes so marked that the curves might well be taken for the work of half a dozen individuals. As far as can be determined, however, these three subjects are the only ones of the twenty-two in the study who fail to produce curves that, in the main, are characteristic for a given individual.

Three factors, either acting singly or in combination, seem to be responsible for most of the daily variation in any one individual's set of curves. These outstanding factors are (1) time of day, (2) type of activity previous to making the record, (3) proximity of work period to food intake. The third factor is probably closely related to both (1) and (2), but its effect upon the work curves is so great that special attention is called to it.

Table II, page 163, summarizes the data contained in the keys to the individual curves (see appendix, pages 261 to 300) relative to the effect of time of day upon the fatigue curve for the dynamometer. If the morning curves for any subject are alike in general, a cross is placed under "similar" in column 1. If they are different, the cross indicates this fact. Similar information is given for noon and afternoon curves in columns 2 and 3. A dash indicates that the subject has no curves at that time of day. Twenty-two subjects have morning curves. Twelve have noon curves, but only seven of these twelve have more than one curve in order for an estimate of "same" or "different" to be made. Twenty-one subjects have afternoon curves. If the curves of any one subject are such that the morning, noon, and afternoon curves fall into a class by themselves, similar to each other but unlike the members of the other two groups, a cross indicates this fact in column 4. A cross in column 5 means that the curves are all similar in general regardless of time of day.

Table II, then, illustrates that for the group studied, the morning curves of any one individual are more apt to be similar, i.e., follow the same general trend, than are the

TABLE II.

The Effect of Time of Day Upon the Fatigue Curve Taken on the Dynamometer

| Subject | 1 Morning Curves | | 2 Noon Curves | | 3 P. M. Curves | | 4 Curves Grouped into A. M., M., and P. M. | 5 Curves not Grouped |
|---|---|---|---|---|---|---|---|---|
| | Similar | Different | Similar | Different | Similar | Different | | |
| I. | X | | | X | X | | X | |
| II. | X | | X | | | X | X | |
| III. | X | | X | | - | - | X | |
| IV. | | X | - | - | | X | | X |
| V. | X | | - | - | X | | X | |
| VI. | X | | (only 1) | | | X | | X |
| VII. | | X | - | - | | X | | X |
| VIII. | X | | - | - | X | | | X |
| IX. | X | | - | - | | X | X | |
| X. | X | | - | - | X | | | X |
| XI. | | X | X | | | X | X | |
| XII. | X | | X | | | X | | X |
| XIII. | X | | (only 1) | | | X | | X |
| XIV. | X | | X | | | X | | X |
| XV. | X | | - | - | X | | | X |
| XVI. | | X | X | | X | | X | |
| XVII. | X | | (only 1) | | X | | | X |
| XVIII. | X | | - | - | X | | | X |
| XIX. | X | | - | - | | X | X | |
| XX. | | X | (only 1) | | | X | | X |
| XXI. | | X | - | - | | X | | X |
| XXII. | | X | (only 1) | | | X | | X |
| No. of cases influenced in each way | 15 | 7 | 6 | 1 | 8 | 13 | 8 | 14 |

% of entire group of 22 affected by time grouping, 8/22, or 36%.

afternoon curves. Curves taken at noon time directly after eating are usually very much alike. On the whole, however, time of day has not much effect upon determining the shape of the curve. Most people (64% in present study) tend to produce the same general curve any time of the day if other conditions are kept constant. The fact that 36% of the group did produce curves, however, which fell into definite time periods is noteworthy in itself. When this occurred, other conditions were fairly constant throughout the day. The time was the single variable. It cannot be said, then, that time of day exerts no effect upon shaping the fatigue curve. The suprising thing is that it exerts as much influence as it does.

Since, however, as Table II illustrates, the similarity of curves is greatest at the noon hour directly after eating, perhaps another factor deserves more credit for much of the influence claimed by factor (1),--namely, the food intake itself. In order to examine this question still further, a comparison was made between the after-dinner (or so-called after eating, or noon curves) of each individual and his other daily curves. This data is summarized in Table III on page 165. The twelve subjects who produced curves directly after eating, are listed, and the degree of difference between their noon curves and their other daily curves is noted. In every instance but three, where there is no change at all, these noon curves are shorter than the other curves. Usually the dropping off is more rapid, and in several instances, the contractions are weaker than usual. At any rate, fatigue is more rapid just after eating in 75% of the cases (9 out of 12) who produce noon curves. This statement

TABLE III.

Effect of Eating Previous to Recording Upon the Shape of the Fatigue Curve Taken on the Dynamometer.

| Subject | Degree of Change |
|---|---|
| I. | Curves shorter than others and more irregular. |
| II. | Curves shorter than others with steeper end drop. |
| III. | Curves shorter than others with steeper end drop, also weaker. |
| VI. | Curve is the shortest of group, and weakest. |
| XI. | Curves shorter than others. |
| XII. | No change. |
| XIII. | No change. (One curve only) |
| XIV. | Shorter and more abrupt than others. |
| XVI. | Shorter and steeper than rest. |
| XVII. | By far the shortest curve, and very abrupt. |
| XX. | No change. (One curve only) |
| XXII. | Curve is shorter and steeper than rest. |

Number of subjects............................12

Number of subjects influenced by eating.......9

% influenced who produce noon curves..........75%

% of entire group influenced by eating........41% (9/22)

Subjects influenced by both time of day and eating, I, II, III, XI, and XVI....5 subjects, or 23% of group.

is equivalent to saying that 41% of the entire group were influenced by eating previous to record taking, as over against 36% who were influenced by time of day alone. Since five individuals (or 23% of the group) are influenced by both factors, and since the eating factor exerts the greater influence upon the group as a whole, 36% is evidently much too high an estimate of the influence of time of day upon the work of the group.

When no food is taken for more than two hours prior to recording, the curves do not show these peculiar characteristics listed in Table III. In the case of Subject IV, (fig. 16, curves 4 and 5), who represents the single instance when the curves are taken just exactly one hour after food intake, the curves again are shorter than the rest of his group, but the differences are not as marked as is in the cases where food intake comes directly before recording. Nothing in the present data indicates that these same conditions would hold if food were taken at any time of day. All twelve cases reported took their records directly after the noon meal only.

A third factor, and probably the most important factor in shaping the fatigue curves on the dynamometer is the type of activity engaged in just previous to record taking. In order to avoid confusion it should be understood that this factor is not meant to include eating as a previous activity. Of the total 161 fatigue curves which go to make up the study upon the dynamometer, 19 were taken after eating. One hundred and forty-two curves were preceded by some other form of activity. Table IV, page 167, again based on the data in the individual keys(appendix, pages 261 to 300 ) indicates the number of curves influenced by

## TABLE IV.

Number of Curves Influenced by Previous Activity (Other than Eating) for Group Working on Dynamometer.

| Subject | Column 1. Number of curves taken after different kinds of work. Gen. Ment. | Int. Ment. | Light Phys. | Hard Phys. | Column 2. Number of curves influenced by activity. Gen. Ment. | Int. Ment. | Light Phys. | Hard Phys. |
|---|---|---|---|---|---|---|---|---|
| I. | 5 | | | 3 | 4 | | | 2 |
| II. | 2 | | 6 | | 1 | | 5 | |
| III. | 3 | 1 | | | 3 | 1 | | |
| IV. | 6 | | 1 | | 5 | | 1 | |
| V. | 8 | | | | 8 | | | |
| VI. | 4 | | | 3 | 3 | | | 2 |
| VII. | 4 | | 4 | | 3 | | 4 | |
| VIII. | 4 | | 2 | | 3 | | 2 | |
| IX. | 6 | | | | 2 | | | |
| X. | 8 | | | | 7 | | | |
| XI. | 5 | | 3 | | 5 | | 1 | |
| XII. | 4 | | | | 4 | | | |
| XIII. | 8 | | | | 4 | | | |
| XIV. | 2 | 1 | | 1 | 2 | 1 | | 1 |
| XV. | 7 | | | | 5 | | | |
| XVI. | 6 | | | | 2 | | | |
| XVII. | 6 | | | | 5 | | | |
| XVIII. | 6 | | | | 5 | | | |
| XIX. | 6 | | | | 4 | | | |
| XX. | 3 | | | 2 | 1 | | | 2 |
| XXI. | | | 1 | 4 | | | 1 | 3 |
| XXII. | 7 | | | | 2 | | | |

| | Gen. Ment. | Int. Ment. | Light Phys. | Hard Phys. |
|---|---|---|---|---|
| Number of curves studied per activity: | 110 | 2 | 17 | 13 |
| Number of curves influenced per activity: | 78 | 2 | 14 | 10 |

Total number of curves taken after mental and physical work: 142

Total number of curves influenced by mental and physical work:... 104

previous activity. In general, the type of work done previous to work on the cynamometer can be classified as follows:

I. Mental Work
  A. General
    1. Attends class
    2. Teaching
    3. Reading, writing
    4. Calculating
    5. Office work
  B. Intense
    1. Examination
    2. Hard study
II. Physical Work
  A. Light (walking, etc.)
  B. Hard
    1. Athletics
    2. Heavy muscular work

Column i of Table IV indicates the number of curves recorded for each subject after general and tense mental work, and light and hard physical work. As column 2 indicates, not all of these curves are actually influenced by the task performed prior to the work period. As the keys to each individual's curves show, there are times when factors other than type of activity are more responsible for the shape of the curve. There are also times when with conditions constant and activity the same, curves differ, seemingly for no apparent reason. It cannot be said definitely, then, that type of activity always makes curves the same or different. For example, note Subject IV (fig. 15, curves 1 and 2). Both curves are taken after similar mental work with other conditions constant, yet the curves are not at all alike. Table IV indicates that of 142 curves studied only 104 of these curves can be listed as being definitely influenced by the type of activity prior to recording. In other words, 76.7% of the 142 curves studied could be said to be alike or unlike chiefly because the type of work was the same or different. In terms of the entire group of 161 curves, however, this average reduces to 64.6%.

Table V, page 170, illustrates more clearly what per cent of the curves are influenced by various factors. Column 1 lists the factors which influence the nature of the curves. Column 2 represents the number of curves studied relative to each factor. Column 3 indicates the number of curves from column 2 which are actually influenced by each factor. Column 4 gives the % of the curves in Column 2 which are influenced by each factor, while Column 5 gives the % of all curves in the dynamometer study which are influenced by each factor. For example, in those curves studied where general mental activity preceded the work period, 71 per cent were similar or different chiefly because the mental task was the same or different before each recording. In terms of the whole group, however, only 48.5% of the curves were thus influenced. When tense mental activity preceded the work period, Table V indicates that all or 100% of the curves were influenced. Since there were only

TABLE V.

Comparison of Factors Influencing the Fatigue Curves Taken on the Dynamometer.

| Col. 1<br>Factors | Col. 2<br>No. of Curves Studied Relative to Each Factor | Col. 3<br>No. of Curves Influenced by Each Factor | Col. 4<br>% of Curves Studied Influenced by Each Factor | Col. 5<br>% of All Curves Influenced by Each Factor |
|---|---|---|---|---|
| General Mental Work | 110 | 78 | 71 | 48.5 |
| Intense Mental Work | 2 | 2 | 100 | 1.2 |
| Light Physical Work | 17 | 14 | 82.3 | 8.7 |
| Hard Physical Work | 13 | 10 | 76.2 | 6.2 |
| All Physical and Mental Work | 142 | 104 | 76.7 | 64.6 |
| Eating | 19 | 15 | 79 | 9.3 |
| Total, including eating. | 161 | 119 | | 73.9 |
| Other Factors... | | 42 | | 26.1 |

two instances in which intense mental work in the form of examination periods was performed prior to recording, this alarming percentage reduces to 1.2% of all curves in the study. Since (as Table V shows) all physical and mental work can account for 64.6% of similarity and dissimilarity in the fatigue curves on the dynamometer and since eating prior to recording can account for another 9.3% of similarity and dissimilarity among the curves, there is still a matter of 26.1% variation to be accounted for. The influence of time of day may account for a small fraction of this percentage. Lack of sleep, introspective judgments of strength and well-being, emotional disturbances, etc., may all enter in as additional small fractions. In all probability, no single factor actually holds the stage alone when these curves are being recorded. But from what has been indicated some factors are more influential than others in affecting the nature of the curves. It is probably true that the most important factor is the type of activity engaged in just previous to recording. Likewise if this activity happens to be food intake, the curve is decidedly influenced. Time of day alone probably exerts a minor influence upon the nature of the work curve.

It is hard to estimate the effects of some of the other variables. Lack of sleep and late parties, as well as plenty of sleep and quiet evenings are often accompanied by a biased estimate of strength and well-being which may or may not affect the curves produced. Curves 8 or Subjects I, II, and VII (fig. 2, 7, and 27) are taken after late parties and lack of sleep and low estimate of strength. Unfortunately, these same curves of Subjects I and II are influenced by food intake as well. Subject VIII, however, falls off from his usual production. Curve 3 of Subject IV is also taken after lack of sleep and late party. The subject estimates his strength as high, however, and produces one of his best records.

The subjects in this study on the whole were more often correct in predicting their performance as foreshadowed in an estimate of strength than they were wrong. Table VI, page 173, indicates roughly the amount of correspondence between each subject's estimate and his performance. A rating of correct signifies positive correspondence for each curve. A rating of always wrong indicates negative correspondence--i.e., if the subject estimates high his production is low and vice versa. More subjects were able to estimate correctly or nearly so more often than not. But perfect correspondence is shown by only six out of twenty-two. Subject II (fig. 6, 7, and 8) who usually estimates correctly, felt very low just before curve 2 because of a sick stomach. The production seemingly was not affected by his condition or belief in his incompetence to produce a good record. Similarly, Subject XIV (fig. 53) whose judgments usually conform to performance, estimates very low in curve 5 because of a head cold. His production is the greatest he has ever shown. On the other hand, Subject XVIII (fig. 64 and 65), who usually estimates incorrectly, felt better than usual before producing curve 4. He estimated his strength at 10 and his record went to the limit of the instrument. Yet he showed no signs of fatigue. He was gripping 21 kilograms when he was stopped and could have continued for an indefinite

TABLE VI.

Subjective Estimates of Strength on Dynamometer.

| Subject | Correct | Usually Correct | Usually Wrong | Always Wrong |
|---|---|---|---|---|
| I. | X | | | |
| II. | | X | | |
| III. | X | | | |
| IV. | | X | | |
| V. | X | | | |
| VI. | | X | | |
| VII. | X | | | |
| VIII. | | | X | |
| IX. | | | X | |
| X. | | X | | |
| XI. | X | | | |
| XII. | | X | | |
| XIII. | X | | | |
| XIV. | | X | | |
| XV. | | X | | |
| XVI. | | | | X |
| XVII. | | X | | |
| XVIII. | | | X | |
| XIX. | | | | X |
| XX. | | | | X |
| XXI. | | X | | |
| XXII. | | | | X |
| | 6 | 9 | 3 | 4 |

period. This was the only one time when the instrument was found lacking to measure complete exhaustion for gripping. It is hard to say, then, how much effect a subject's ideas and general well-being have upon the type of performance he will exhibit at any particular time. And it is almost useless to make a generalization from the data as it stands.

Lack of sleep seems to affect some individuals. Other individuals like Subject IV (fig. 15 and 16) seem to produce their best work after late hours. Subject XVI (fig. 58 and 59) hardly ever slept more than four or five hours except on week-ends when she reports eight and nine. The amount of sleep seems to have no effect upon her records.

General excitement and emotional tension similar to that resulting from an examination period seem to have a similar effect upon the fatigue curves. A very high level of work is maintained for a brief period, the curve drops rapidly after that but usually continues irregularly for a longer period than usual. Subjects II (6), III (3), and VI (8) illustrate this point.

Hard physical work also effects most subjects similarly. The curves follow the same trend as those discussed in emotional excitement, except the curves tend to be shorter rather than longer than usual. Subjects XIV (6), XX (2) illustrate this condition.

In only one instance was it possible to get a record of the influence of time and age upon the fatigue curve. The curves of Subject X (figures 34 to 41) present an interesting study. The work curves in Fig. 34 to 35 are the curves produced in the present study. In every instance his maximum contraction appears first followed by a definite initial spurt. Usually a long plateau follows the initial spurt before the curves go into a final gradual decline. It must be remembered that each two successive grips have been averaged to plot these curves, so that the initial drop in every instance should be greater and the curves should be longer than they are represented here if each grip were plotted singly. Curves in Figures 36 and 37 represent work done by the subject upon a similar instrument in 1914, twenty-three years before, when he was twenty-eight years old. These curves are plotted grip for grip--i.e., each contraction is represented singly. In each instance, the maximum contraction again appears first, the initial drop is greater than at present, but the plateau and general gradual decline follow as usual. Figure 38 illustrates these same curves foreshortened by averaging each successive two grips. The initial drop is somewhat lessened because of the averaging, but it is still greater than what the subject produces at present. Likewise, the initial contraction is always greater than what the subject produces now. These conditions may be explained either because of the difference in instruments or because of the age difference. The chances are, more influence is asserted by the former factor. Even now the subject at the age of 52 can grip 70 to 75 kilograms if his mental set is for one grip only. If he is set for continual gripping, his initial contraction falls in the fifties, and when it is averaged with his second contraction, drops to the forties. Figure 39 represents the subject's average curve in the present study as compared with his average curve in 1914. It will be seen that his earlier curve is shorter, with a higher maximum contraction and a steeper drop than at present. This no doubt can be attributed directly to a difference in the two instruments. Otherwise, when the two curves are examined their points of fluctuation correspond so very closely as to leave no doubt that the same subject is performing. In both the early study and the present study, his individual daily curves are so much alike that one would certainly expect a close degree of correspondence. The subject's living habits are quite constant from day to day at present. Whether they were in 1914 is hard to say but his daily curves seem to indicate that such an assumption is highly possible. Evidently, in this instance at least, the elapse of time and the increase in age have no effect upon the fatigue curve resulting from work upon the dynamometer.

Individual characteristics are certainly present in most of these curves. Whether a fatigue curve can be said to be indicative of any personality trend is simply a matter of conjecture. The writer knows all of the twenty-two subjects quite intimately. It may be a matter of personal bias, then, if interpretations relative to personality are drawn from the curves. This impression results from working with the subjects; however, those individuals (e.g., Subjects V, VI, X, and XV) who are normally very steady and reliable in daily routine can be depended upon to produce very similar curves. Subject V goes so far as to produce a particular curve for morning work, and a very different curve in the afternoon. The morning curves are always similar to each other, and the same condition holds in the afternoon.

Three of the subjects who as a rule could not be relied upon in everyday situations likewise tended to produce very erratic work on the dynamometer--no curve actually followed the same general trend twice. But again, these opinions may be highly colored and quite unreliable.

A few of the subjects show some very definite trends in their daily performance that should be noted before passing to a consideration of holding effects. Subjects I, XI, XIII, and XIV show definite and customary warming-up. Some of the warming-up in the cases of Subjects XI and XIII may not be as great as it appears because of concomitant practice effect. Subjects IX, X, and XIX also show improvement in performance due to practice effect. A few subjects, IV, VII, XII, and XVIII actually seem to get weaker from day to day. Initial spurt is not common, but is customary in the curves of Subjects X, XII, and XVI. Many subjects exhibit an occasional end spurt but in a few cases it seems to be a customary procedure. In spite of the fact that each subject was asked to pull his maximum each time, some subjects almost fatigue and then put on additional steam toward the end. Short end spurts are quite common for Subject XV as well as for III, IV, XI, and XVIII. The number of subjects showing any of these special phenomena is on the whole relatively small so that one would not expect the general fatigue curve for work on the dynamometer to exhibit any of these trends too strongly. As a matter of fact, the general curve in the present study does exhibit a decided end spurt, but as will be shown later, this is chiefly because of an artifice in averaging whereby the longer curves of a few individuals influence the group tendency.

Table VII, page 179, indicates the most important holding trends in the fatigue curve resulting from work on the dynamometer. Again this data is drawn from the curves themselves (Figures 1-76) and from the keys in the appendix. Column 1 lists the subjects; column 2 tells whether, on the whole, the subject's holding curves were similar or not. If the holding curves of any subject are similar and the fatigue curves of which they are a part are also similar, this fact is checked under "yes" in column 3. "No" in column 3 is checked if the subject's holding curves are similar but the corresponding fatigue curves are unlike. In column 4, are listed the subjects whose holding curves are unlike. If the holdings are unlike and the corresponding fatigue curves are unlike, "yes" is checked. If the holdings are unlike but the fatigue curves are alike, "no" is checked. Column 5 lists these subjects with even holding, and column 6, those with irregular holding. Columns 7 and 8 indicate the subjects with high and low holding repectively. Column 9 indicates those subjects who begin to hold high early in the curve. Column 10 lists those who start their curves with little or no holding. The last three columns indicate the general trend and ending of each subject's holding curves. Analysis shows that most holding curves are of three general types. A subject tends, as a rule, to produce some one of these three types. The curve may start low with little or no holding, and then rise gradually as the subject holds more

TABLE VII. Holding Trends in the Fatigue Curves Resulting from Work on the Dynamometer.

| 1 Subj. | 2 Hold. Curves Sim. Yes | 2 Hold. Curves Sim. No | 3 Holding Similar & Curves Similar Yes | 3 Holding Similar & Curves Similar No | 4 Holding Unlike, Curves Unlike Yes | 4 Holding Unlike, Curves Unlike No | 5 Hold. Even | 6 Hold. Irreg-ular | 7 Hold. High | 8 Hold. Low | 9 Starts High | 10 Starts Low | 11 Type I Low be-ginning gradual rise to end. | 12 Type II high start drops, then grad. rise to end. | 13 Type III Low End |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I. | | X | | | X | | | X | | X | | X | | | X |
| II. | | X | | | | X | | X | | X | | X | X | | |
| III. | | X | | | | X | | X | X | | X | | | | X |
| IV. | X | | X | | | | X | | | X | | X | X | | |
| V. | X | | | X | | | X | | | X | | X | X | | |
| VI. | X | | X | | | | | X | | X | X | | | X | |
| VII. | | X | | | | X | | X | | X | X | | | X | |
| VIII. | X | | X | | | | X | | | X | | X | X | | |
| IX. | | X | | | X | | | X | X | | X | | | X | |
| X. | X | | X | | | | | X | X | | | X | X | | |
| XI. | X | | | X | | | | X | | X | | X | | | X |
| XII. | X | | X | | | | X | | X | | | X | X | | |
| XIII. | | X | | | | X | | X | X | | | X | X | | |
| XIV. | | X | | | X | | | X | X | | X | | | X | |
| XV. | X | | X | | | | X | | X | | | X | X | | |
| XVI. | | X | | | X | | | X | X | | | X | X | | |
| XVII. | X | | X | | | | X | | | X | | X | X | | |
| XVIII. | X | | X | | | | X | | | X | X | | | X | |
| XIX. | X | | | X | | | X | | | X | | X | X | | |
| XX. | | X | | | X | | | X | X | | X | | | X | |
| XXI. | | X | | | X | | | X | | X | | X | X | | |
| XXII. | X | | | X | | | X | | X | | X | | | | X |
| | 12 | 10 | 8 | 4 | 6 | 4 | 9 | 13 | 10 | 12 | 8 | 14 | 12 | 6 | 4 |

and more with the onset of fatigue. This trend is called Type I. A second trend, Type II, shows early high holding which does not last for long before the subject relaxes again (in some cases quite completely) for a short time, and then begins to hold more and more as he fatigues. A third type, an indefinite category, is some sort of an irregular curve sometimes like Type I, and sometimes like Type II, but the subject tends to hold less toward the end as he fatigues.

It will be recalled that by holding was meant the inability of the subject to relax completely between grips so that the hand of the instrument did not go back clear to the base line. In the work on the dynamometer every single subject exhibits this holding in one form or another. No one seems to be able to relax entirely, especially as fatigue sets in. As most subjects expressed it, the attitude of "I can't relax, my muscles are tightening up", was common toward the close of the work periods. The holding curves like the fatiuge curves show great variation from individual to individual, but the personal characteristics of the curves are not as distinct as in the case of the actual fatigue curves themselves. Of the twenty-two subjects, twelve tend to produce holding curves that do not vary much from day to day (column 1, Table VII). The holdings among individuals vary--but not the subject's holdings among themselves, at least not in the case of twelve subjects. The other ten subjects produce holding curves from day to day which are more often unlike. Of the twelve who produce similar holdings, eight, or 66% produce similar fatigue curves. In terms of the entire group, then, 36% who produce similar holding curves likewise produce similar fatigue curves (see column 2, Table VII). Of the ten who produce unlike holdings, six (column 3, Table VII), or 60%, also produce unlike fatigue curves. In terms of the entire group this percentage reduces to 28%. In all, then, 64% of the subjects indicate a positive relationship between the type of holding and the type of fatigue curve they produce. No correspondence between holdings and the general nature of the fatigue curves is found in 36% of the subjects. Holding is more often irregular than ever, but the chances are about 50/50 as to whether it will be high or low. A subject usually produces either all high or all low holdings, as a rule, but there are exceptional curves which do not run true to form. In the present study the majority start their fatigue curves with little or no holding. 86% of these subjects produce a Type I curve. The remaining few (2 cases) fall into the Type III category. Of those subjects who start their holding high, 75% produce a Type II curve--the rest (again 2 cases) fall into the Type III class.

In general, two types of holding are common with Type I, as described above, predominating. In general, also, if a subject's holding curves are either all different or all the same, his fatigue curves will likewise follow a similar arrangement.

The holding of Subject III (Figures 13 and 14) is an interesting study. This subject had difficulty in learning to relax. If he relaxed, he lost rhythm. If he kept his rhythm, he held abnormally high. The early curves in Figure 13 illustrate this abnormally high holding. The subject was quite aware of his difficulty and bent every effort to relax more and more. Curve 4, Figure 13, indicates the usual high holding, but there is a sudden drop as the subject was instructed to relax. Here for the first time he had gotten the "feel" of relaxing between grips. Curves 5 and 6, Figure 14, are quite normal, but the tendency to get off to a high start is present. This high holding had no real detrimental effect on the fatigue curve, however. When the subject was completely exhausted, his curve was of average length, but he had done more work than the average subject, for usually he was still gripping 12 to 18 kilograms in the final contraction. The fact which is illustrated here is that, with conscious effort, holding can be reduced considerably. Relaxation between grips can be learned. This is the only instance in the study of the dynamometer where a subject was coached in this respect. Nothing was said to the other subjects relative to holding.

The plates included in the next few pages will, no doubt, make clear some of the trends of holding curves as discussed above.

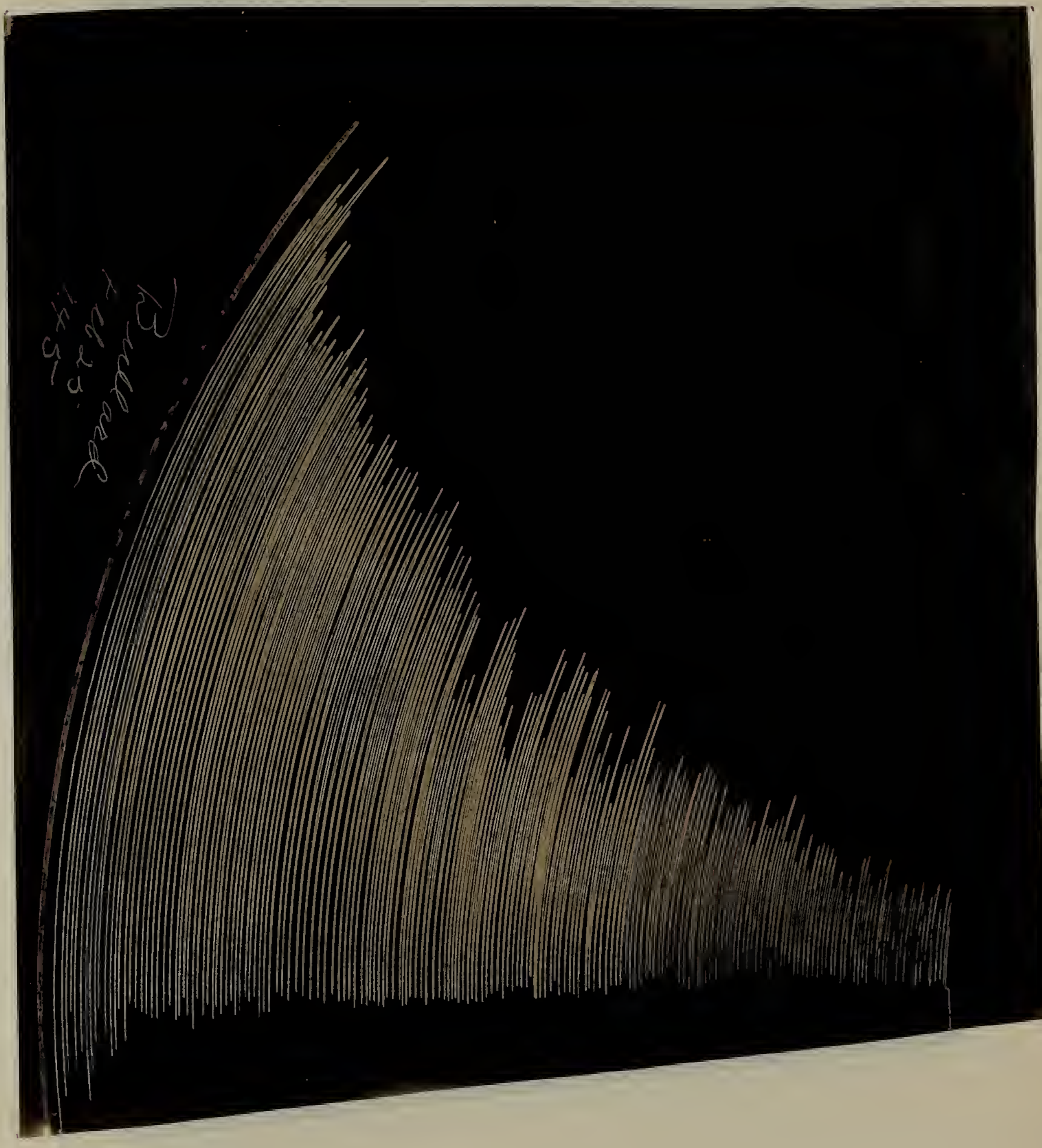
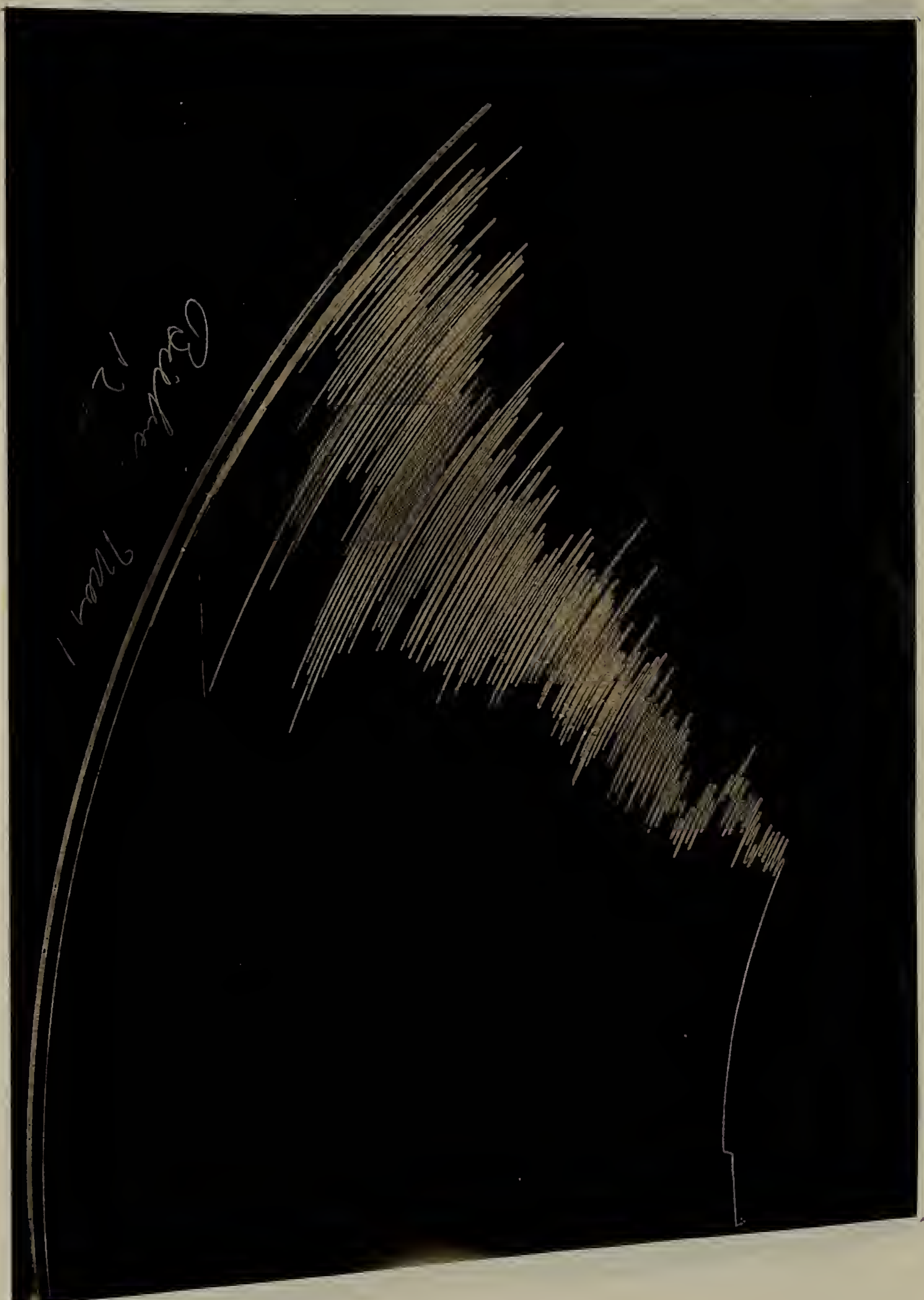



PLATE 9

Illustrating low, even holding.



P L A T E  1 0

Illustrating abnormally high holding.

PLATE 11

Illustrating Type I holding.

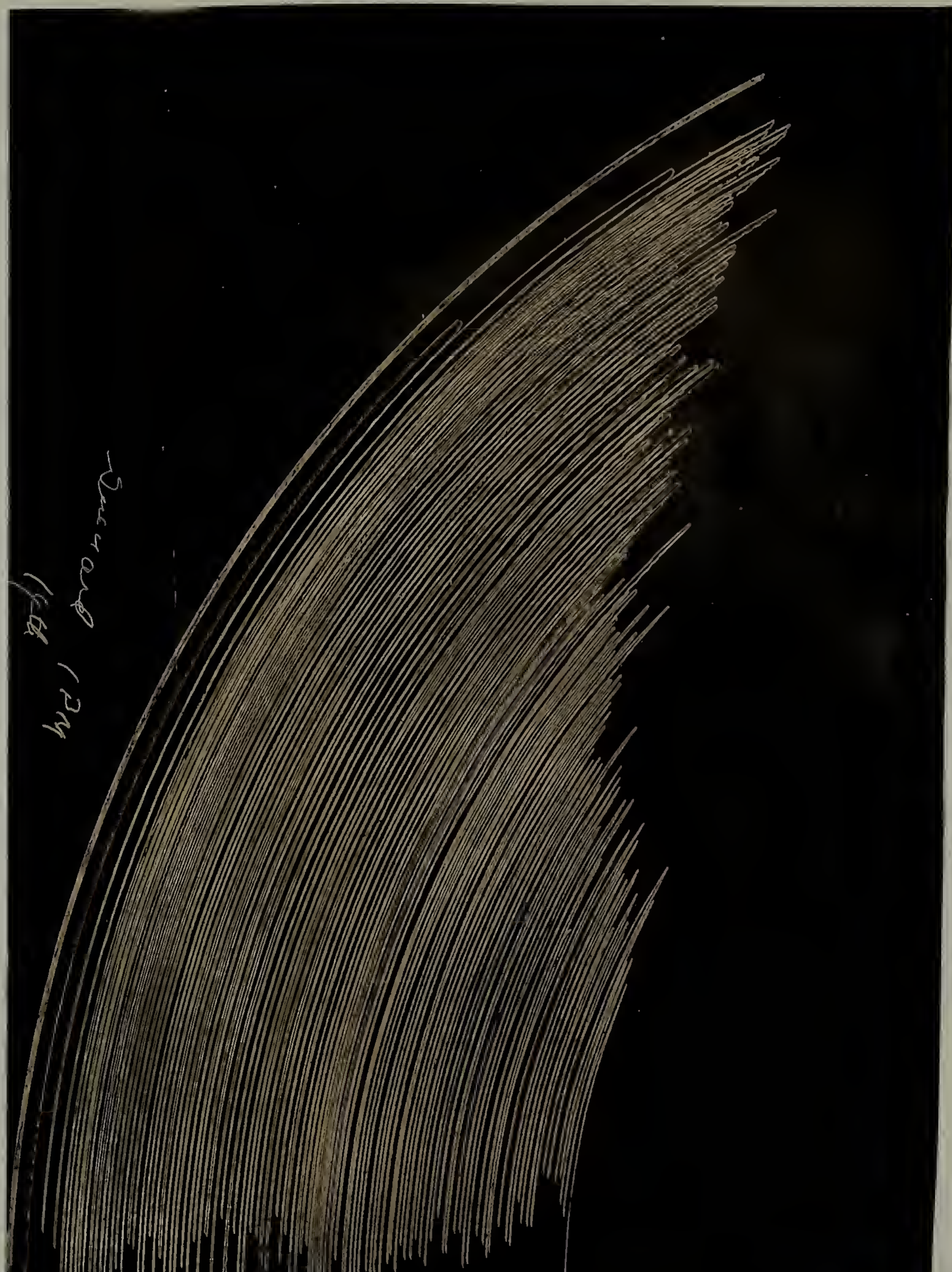


PLATE 12

Illustrating Type II holding.

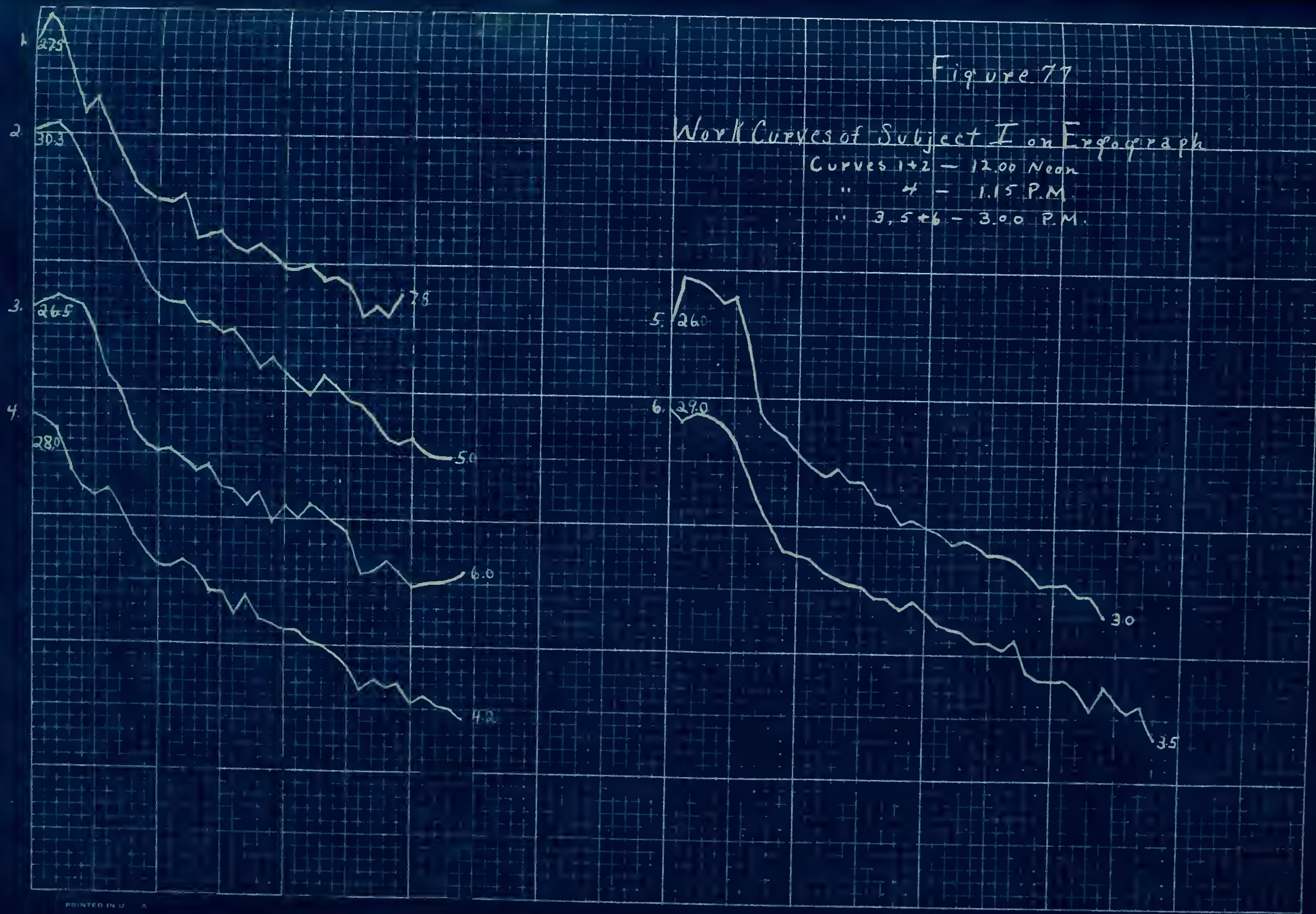


Figure 77
Work Curves of Subject I on Ergograph
Curves 1+2 – 12.00 Noon
" 4 – 1.15 P.M.
" 3, 5 + 6 – 3.00 P.M.
1. 27.5
7.8
2. 30.3
5.0
3. 26.5
6.0
4. 28.0
4.2
5. 26.0
3.0
6. 29.0
3.5

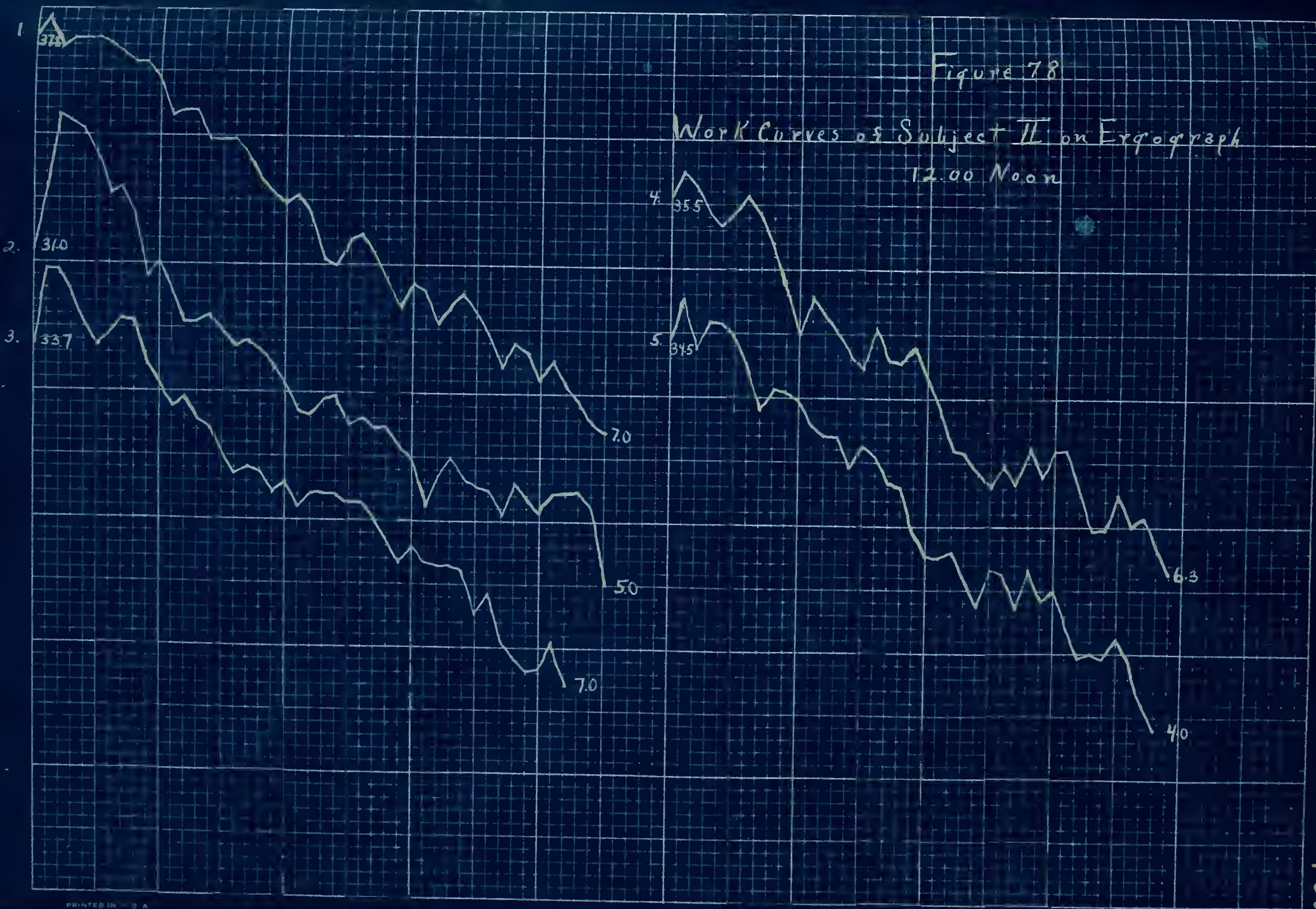



Figure 78

Work Curves of Subject II on Ergograph
12.00 Noon

Figure 79

Work Curves of Subject II on Ergograph
3.00 P.M.

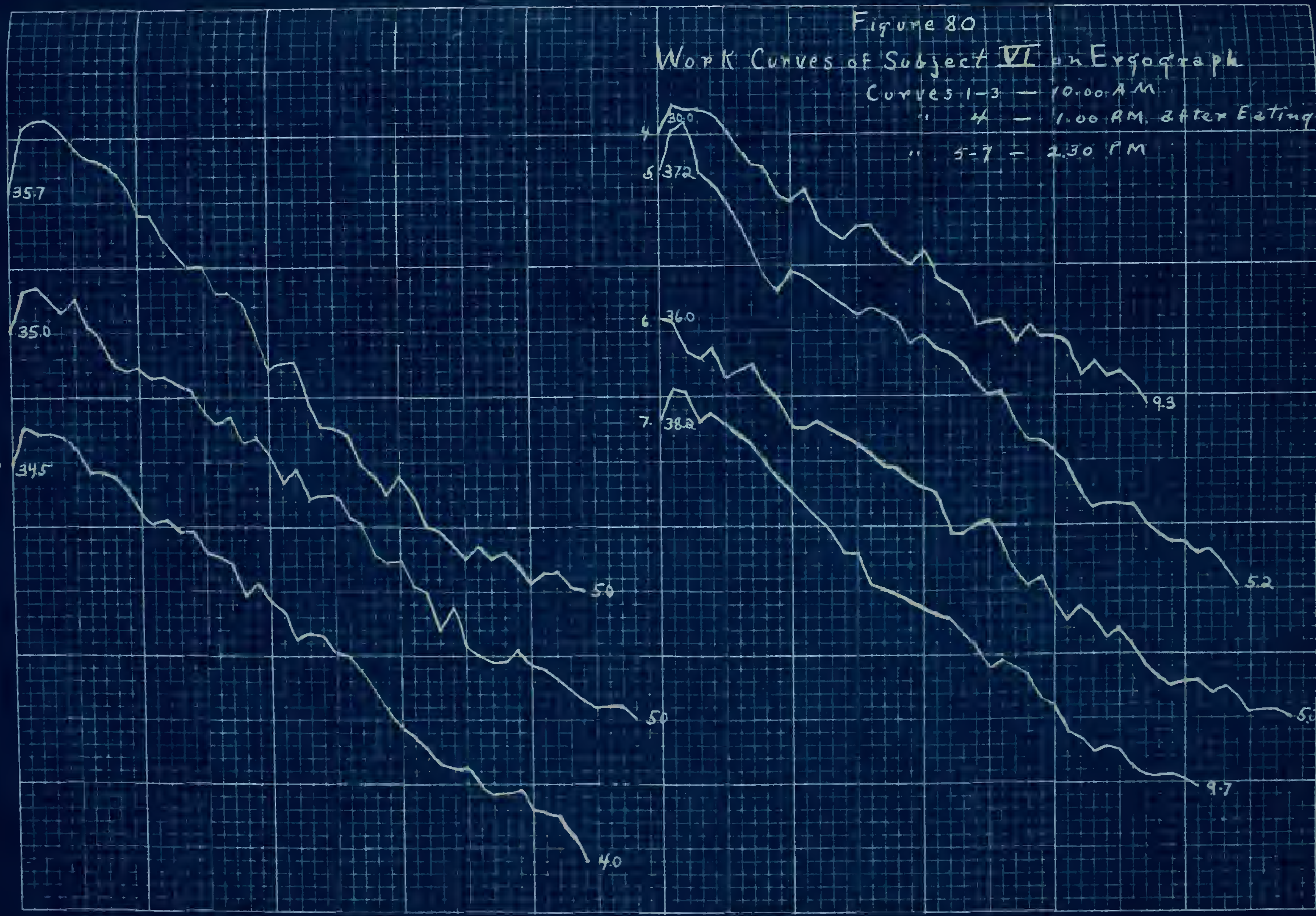



Figure 80

Work Curves of Subject VI on Ergograph

Curves 1–3 — 10.00 A.M.

" 4 — 1.00 P.M. after Eating

" 5–7 — 2.30 P.M.

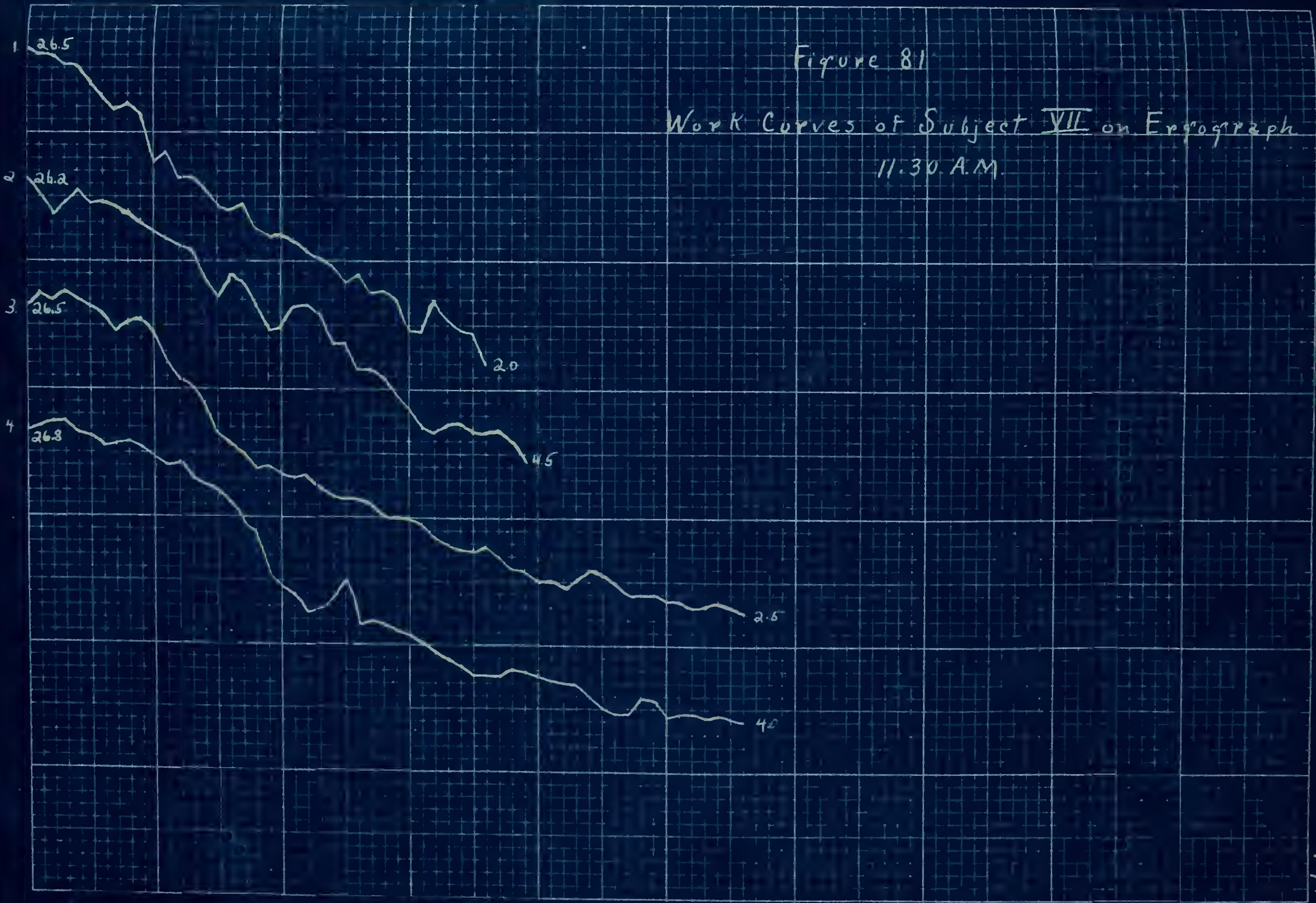



Figure 81

Work Curves of Subject VII on Ergograph

11.30 A.M.

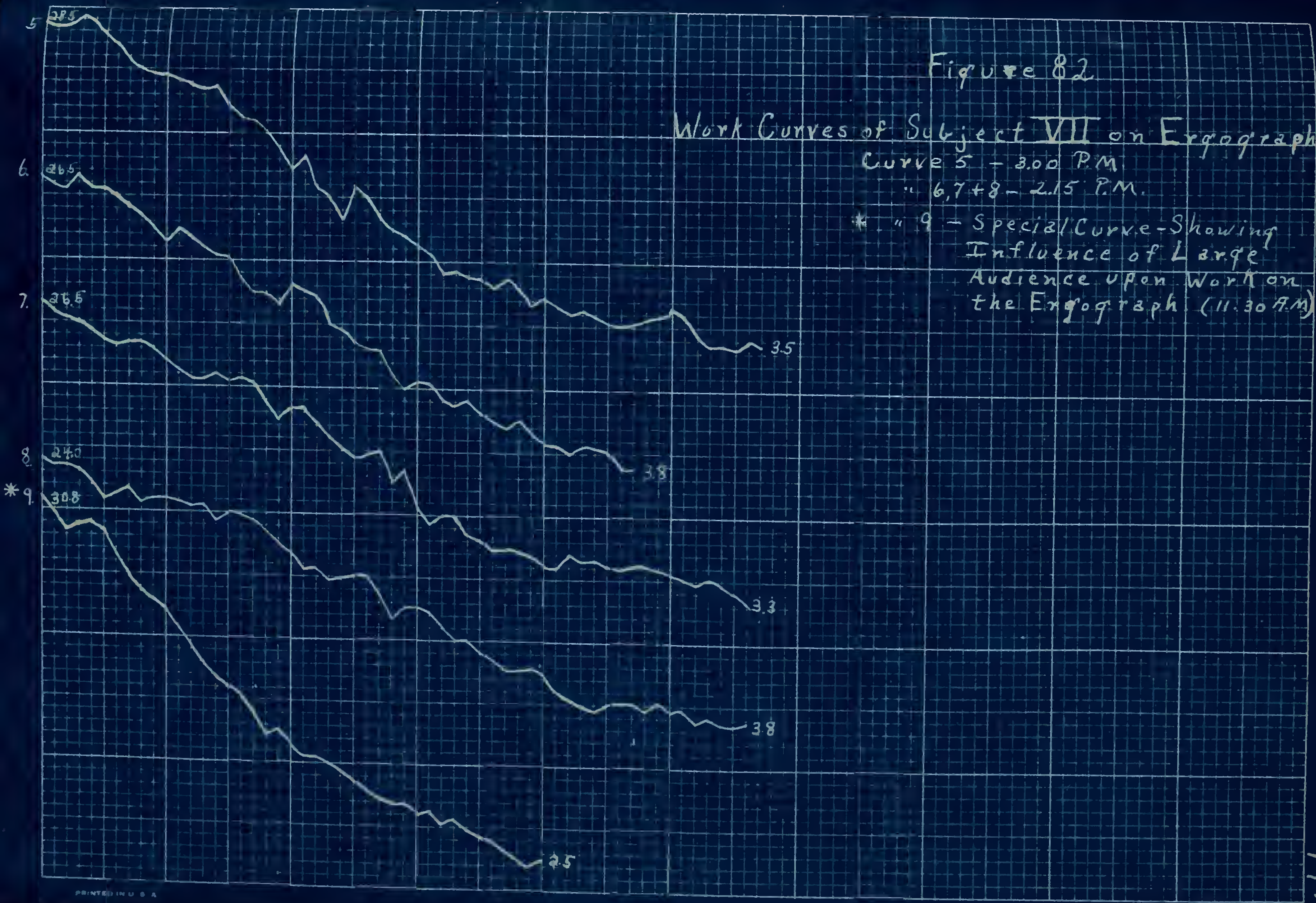



Figure 82

Work Curves of Subject VII on Ergograph

Curve 5 – 3.00 P.M.

" 6,7+8 – 2.15 P.M.

* " 9 – Special Curve – Showing Influence of Large Audience upon Work on the Ergograph (11.30 A.M.)

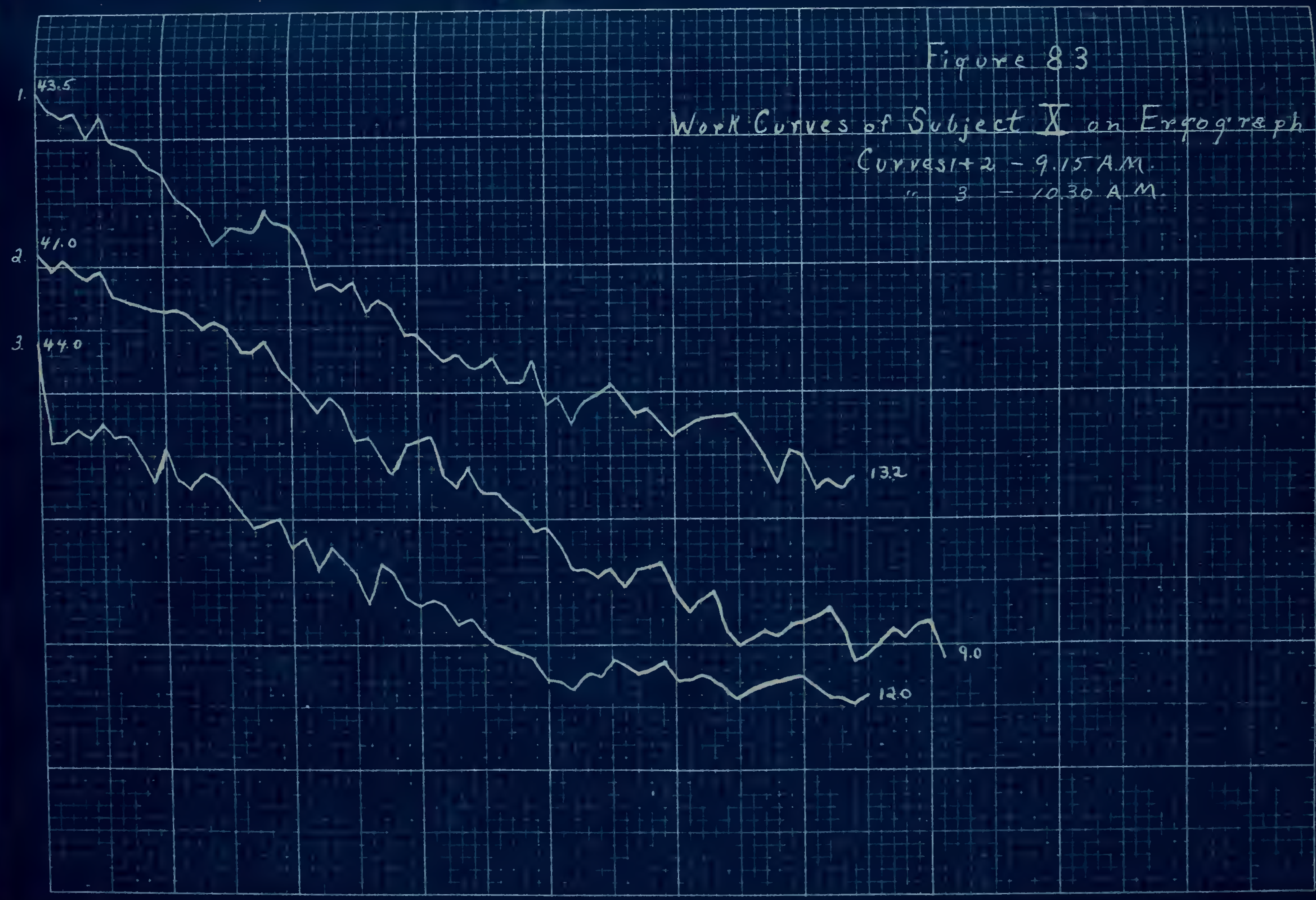



Figure 83

Work Curves of Subject X on Ergograph

Curves 1 + 2 – 9.15 A.M.
" 3 – 10.30 A.M.

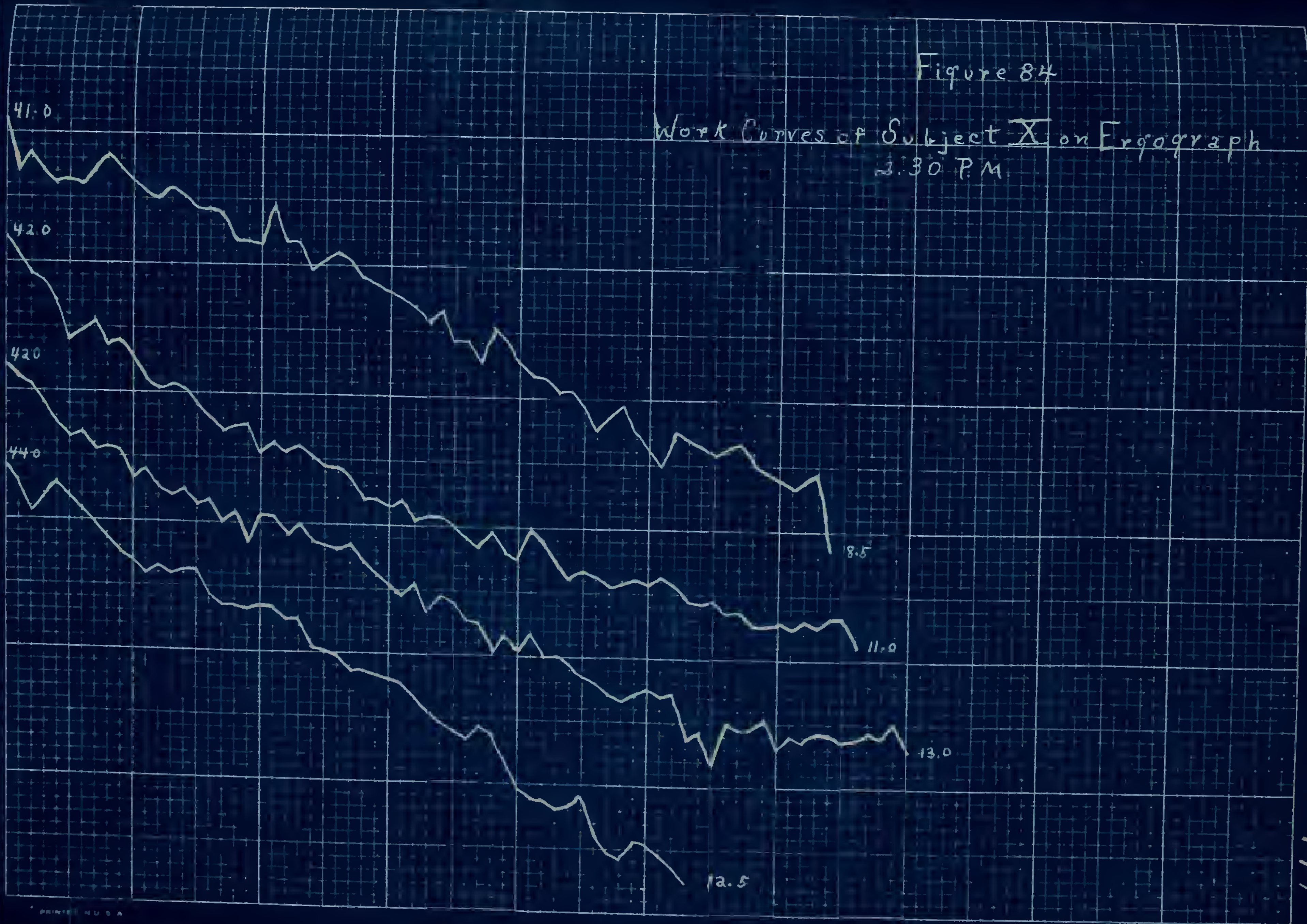



Figure 84

Work Curves of Subject X on Ergograph
3.30 P.M.

Figure 85

Work Curves of Subject XI on Ergograph

11.00 A.M.


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Figure 86
Work Curves of Subject XI on Ergograph
Curves 5, 6 + 8 – 2.00 P.M.
" 4 – 2.45 P.M.
" 7 – 3.15 P.M.
4.
40.5
5.
27.5
6.
24.0
7.
20.0
8
27.0
15.7
7.5
6.5
7.5
8.0

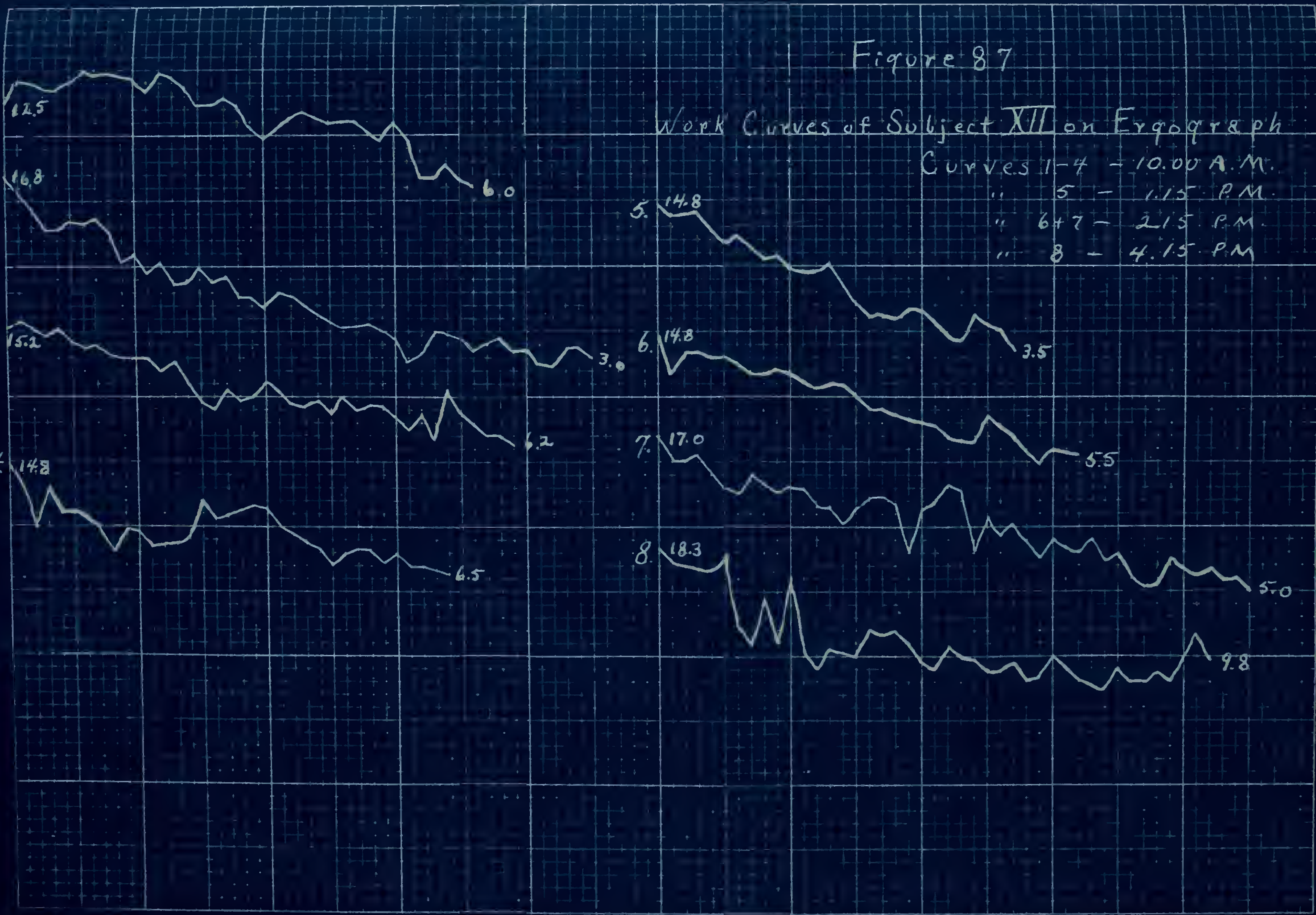



Figure 87

Work Curves of Subject XII on Ergograph


Figure 88

Work Curves of Subject XIV on Ergograph

9.45 A.M.

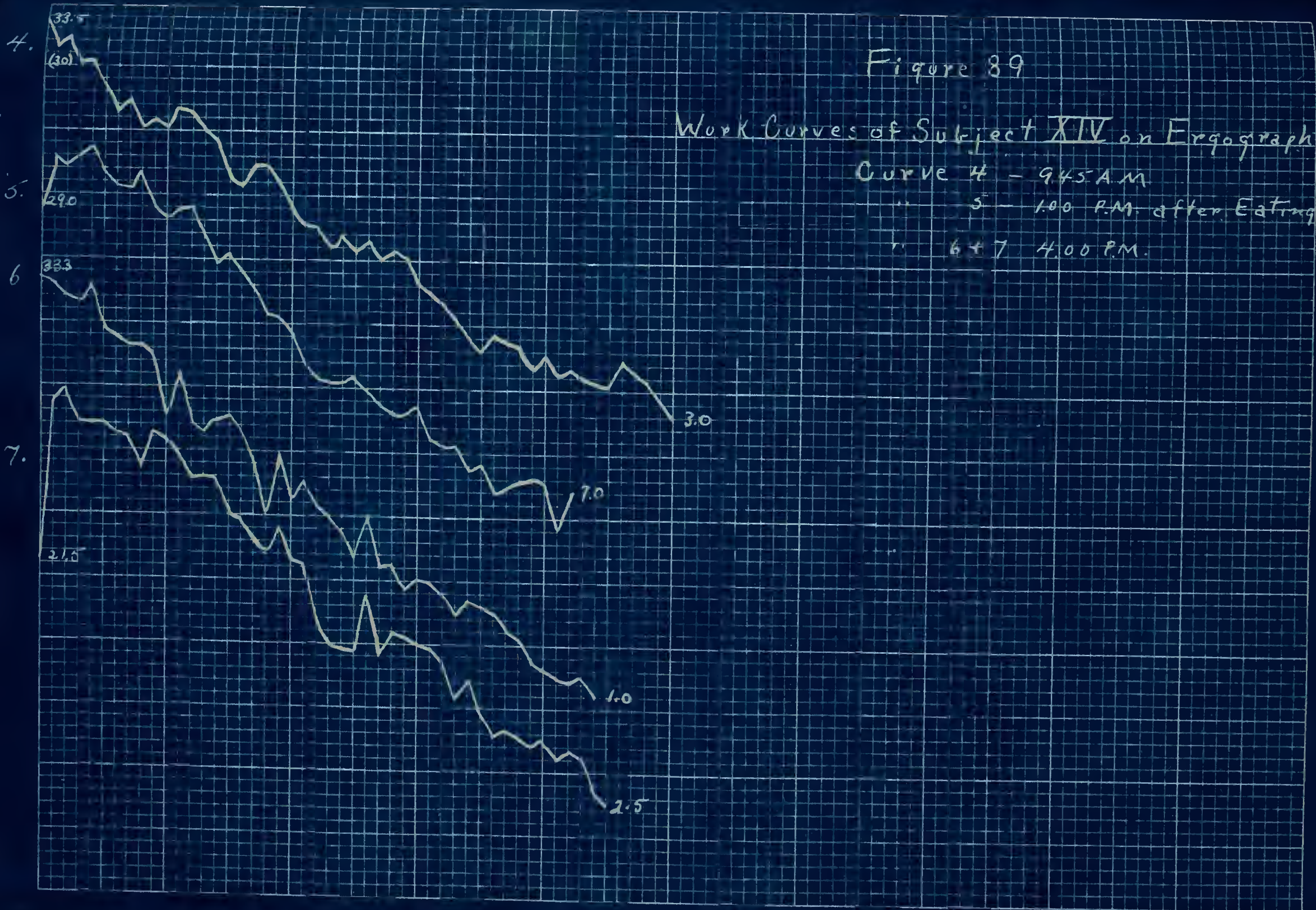
Figure 89

Work Curves of Subject XIV on Ergograph

Curve 4 – 9.45 A.M.

" 5 – 1.00 P.M. after Eating

" 6 + 7 4.00 P.M.



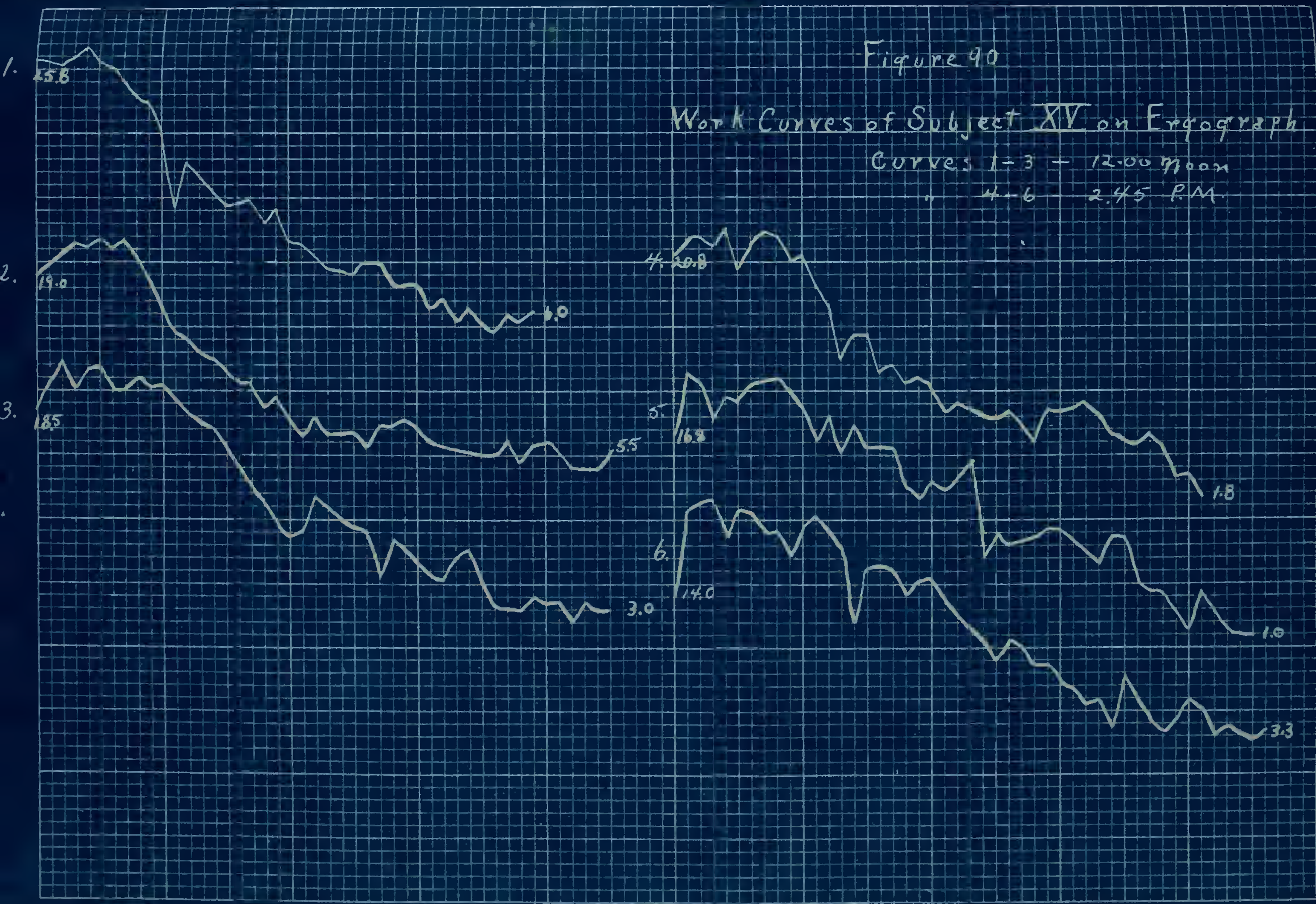



Figure 90

Work Curves of Subject XV on Ergograph

Curves 1-3 — 12.00 noon
" 4-6 — 2.45 P.M.

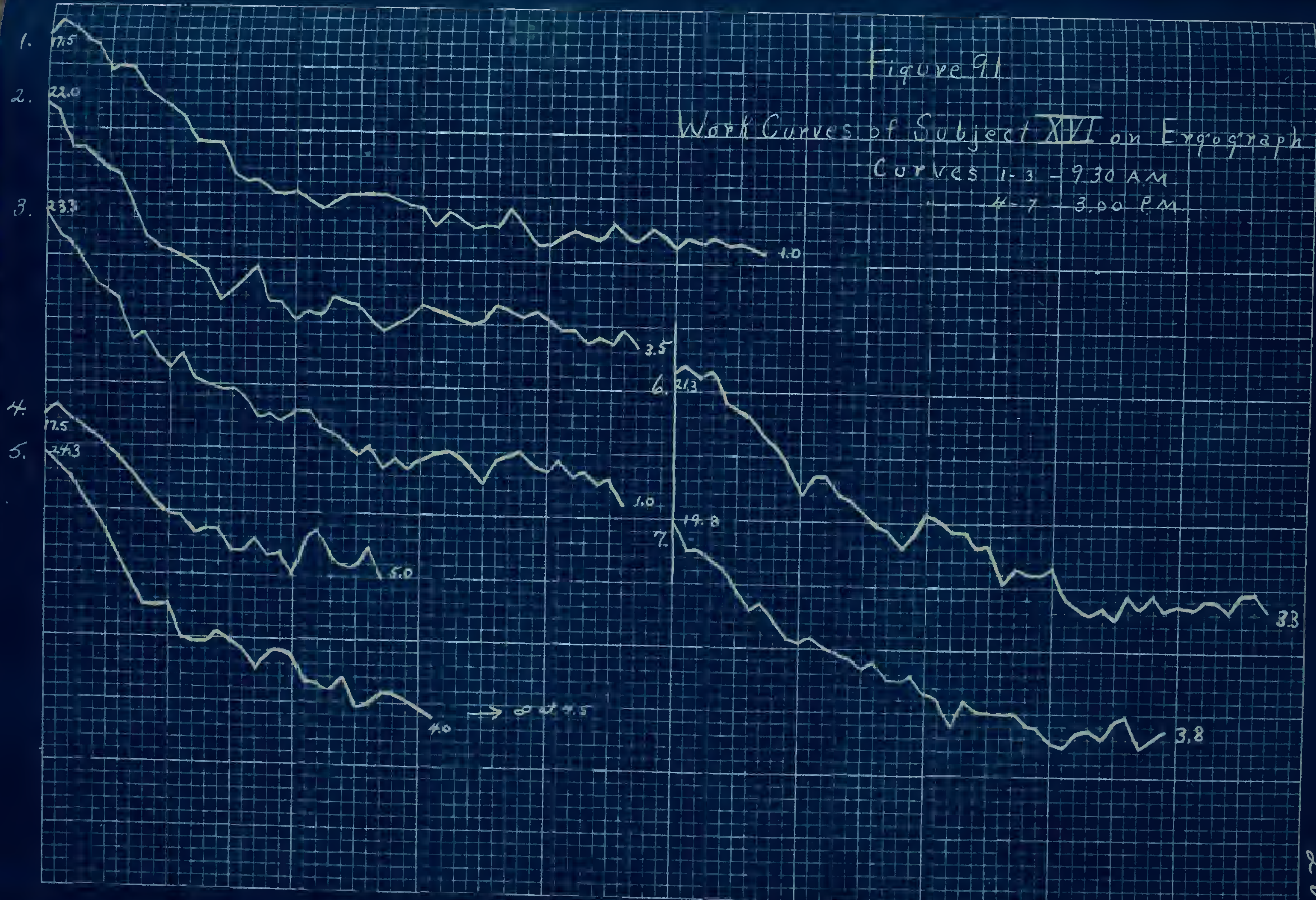



Figure 91

Work Curves of Subject XVI on Ergograph

Curves 1-3 – 9.30 A.M.

4-7 – 3.00 P.M.

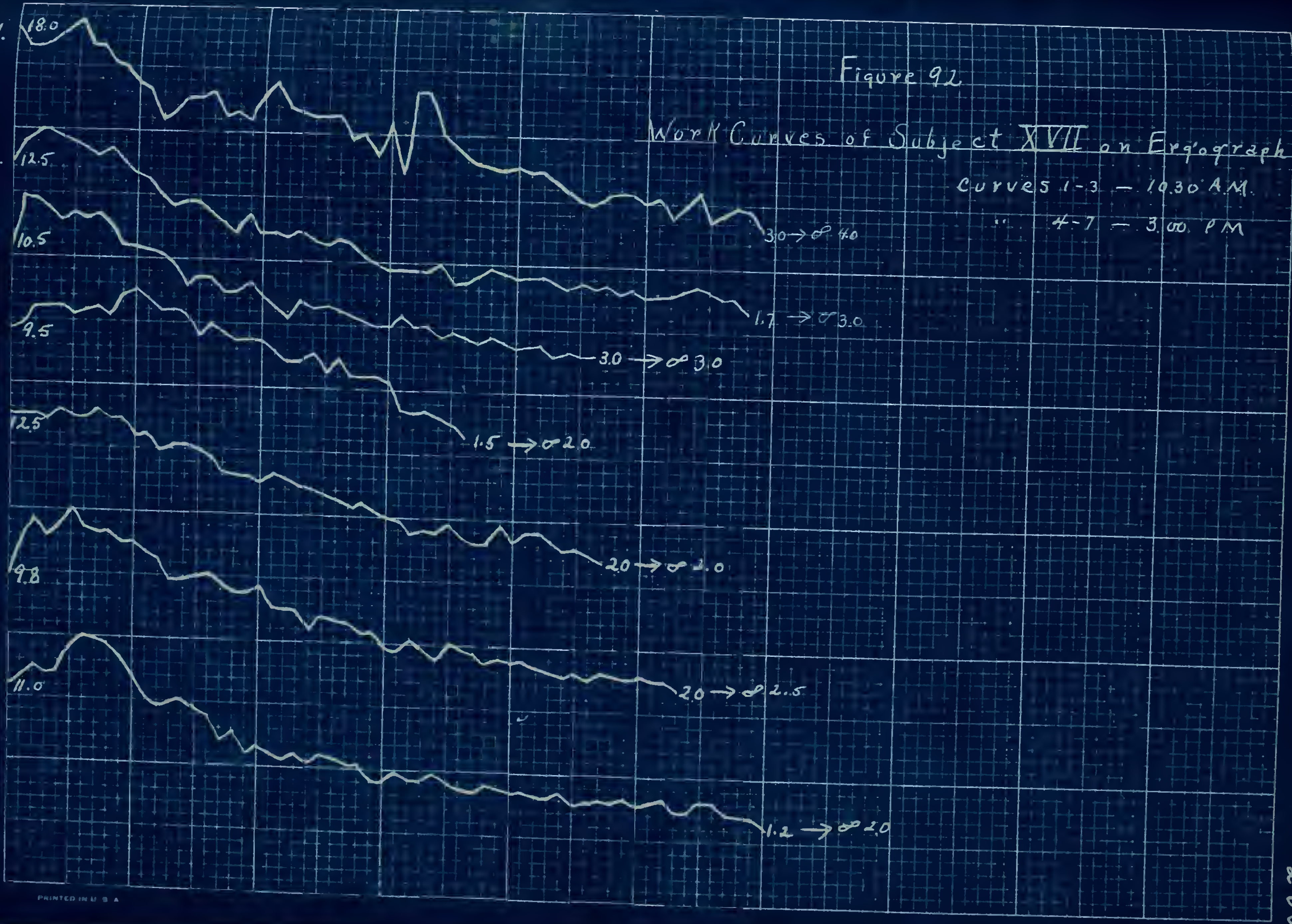



Figure 92

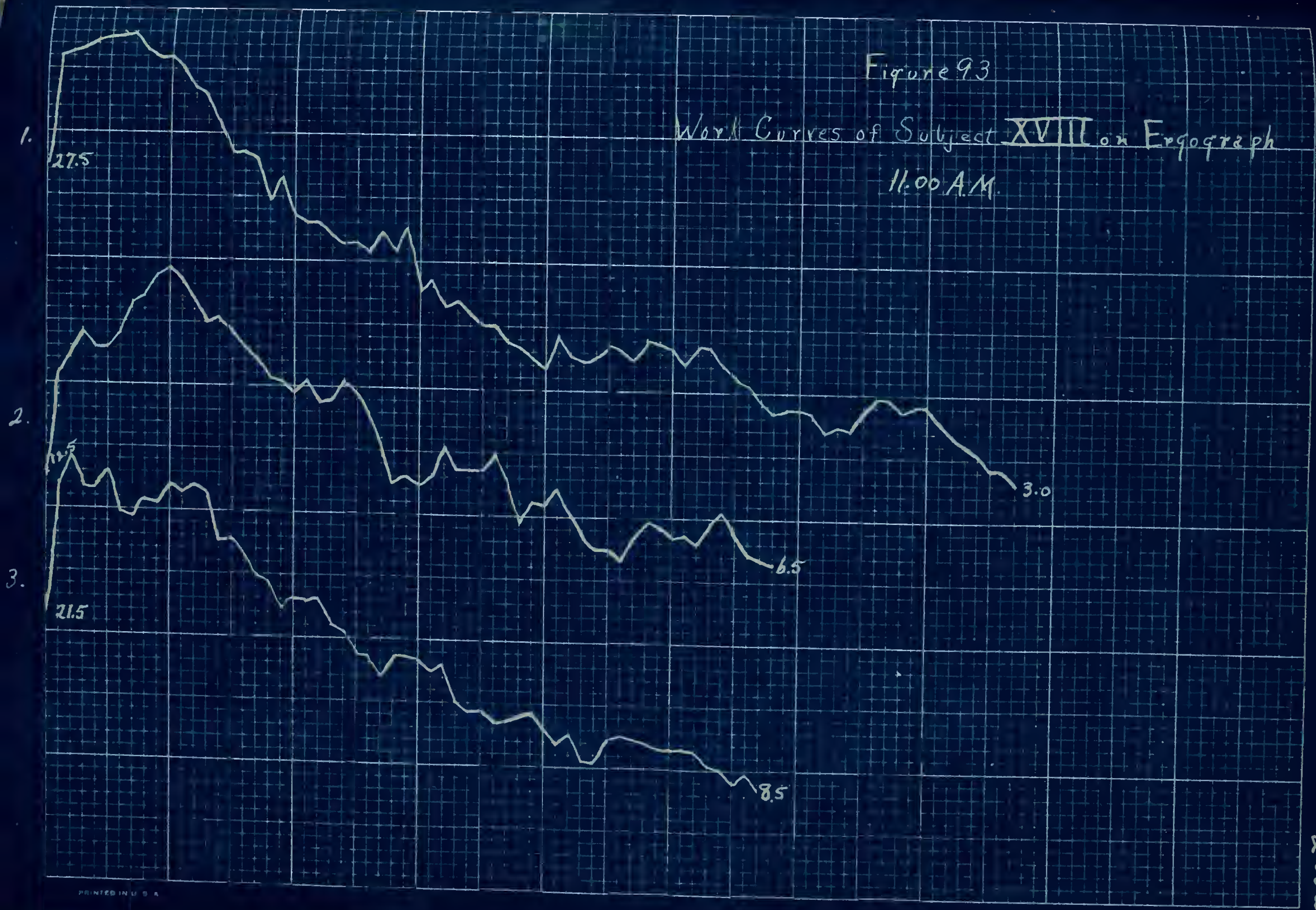
Work Curves of Subject XVII on Ergograph

Curves 1-3 — 10.30 A.M.
" 4-7 — 3.00 P.M.

Figure 93

Work Curves of Subject XVIII on Ergograph

11.00 A.M.



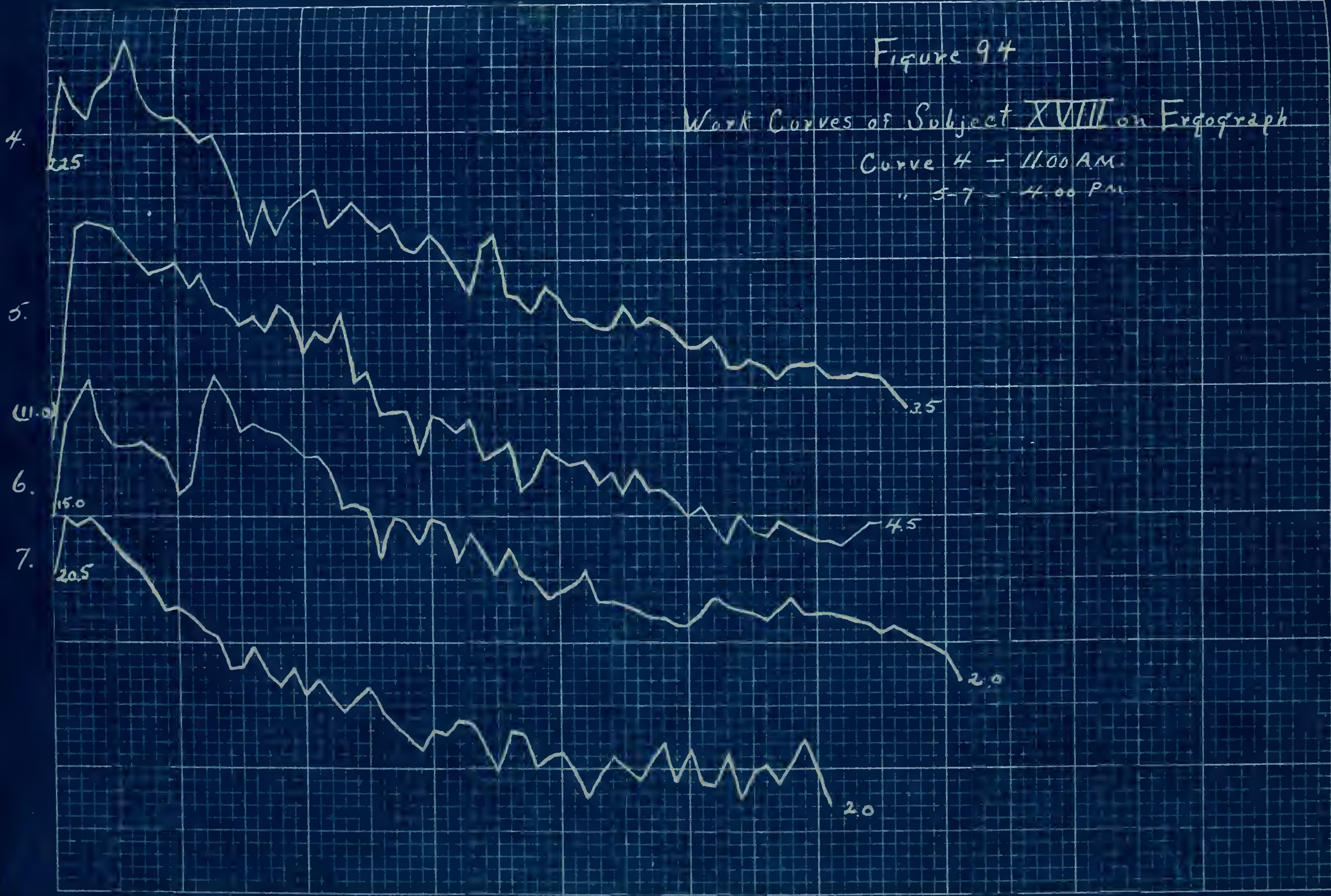



Figure 94

Work Curves of Subject XVIII on Ergograph

Curve 4 — 11.00 A.M.
" 5-7 — 4.00 P.M.

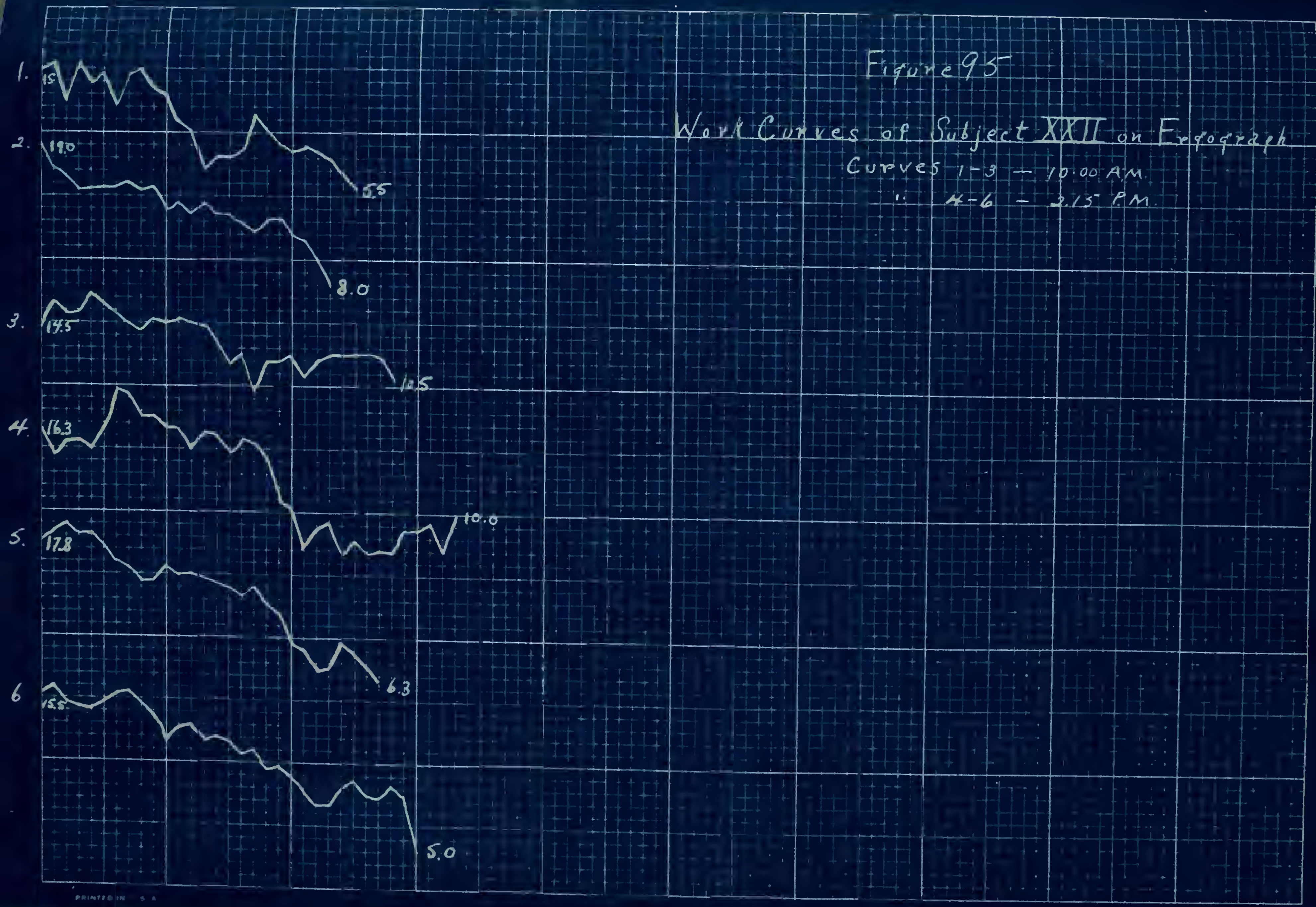


Figure 95
Work Curves of Subject XXII on Ergograph
Curves 1-3 — 10:00 A.M.
" 4-6 — 2:15 P.M.
1. 15
5.5
2. 19.0
8.0
3. 14.5
12.5
4. 16.3
10.0
5. 17.8
6.3
6 15.5
5.0

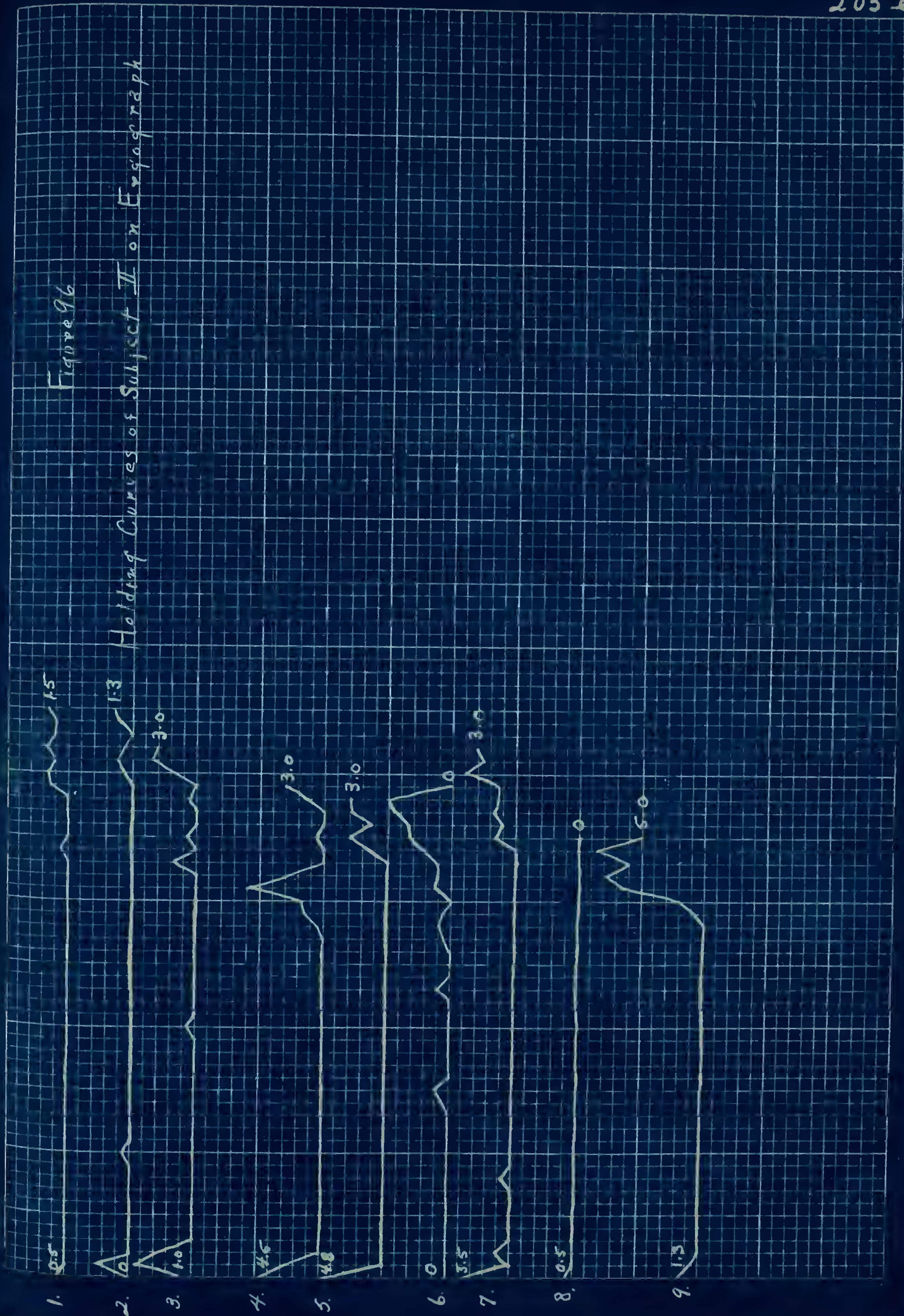



Figure 96
Holding Curves of Subject II on Ergograph

Figure 97

Holding Curves of Subject X on Ergograph

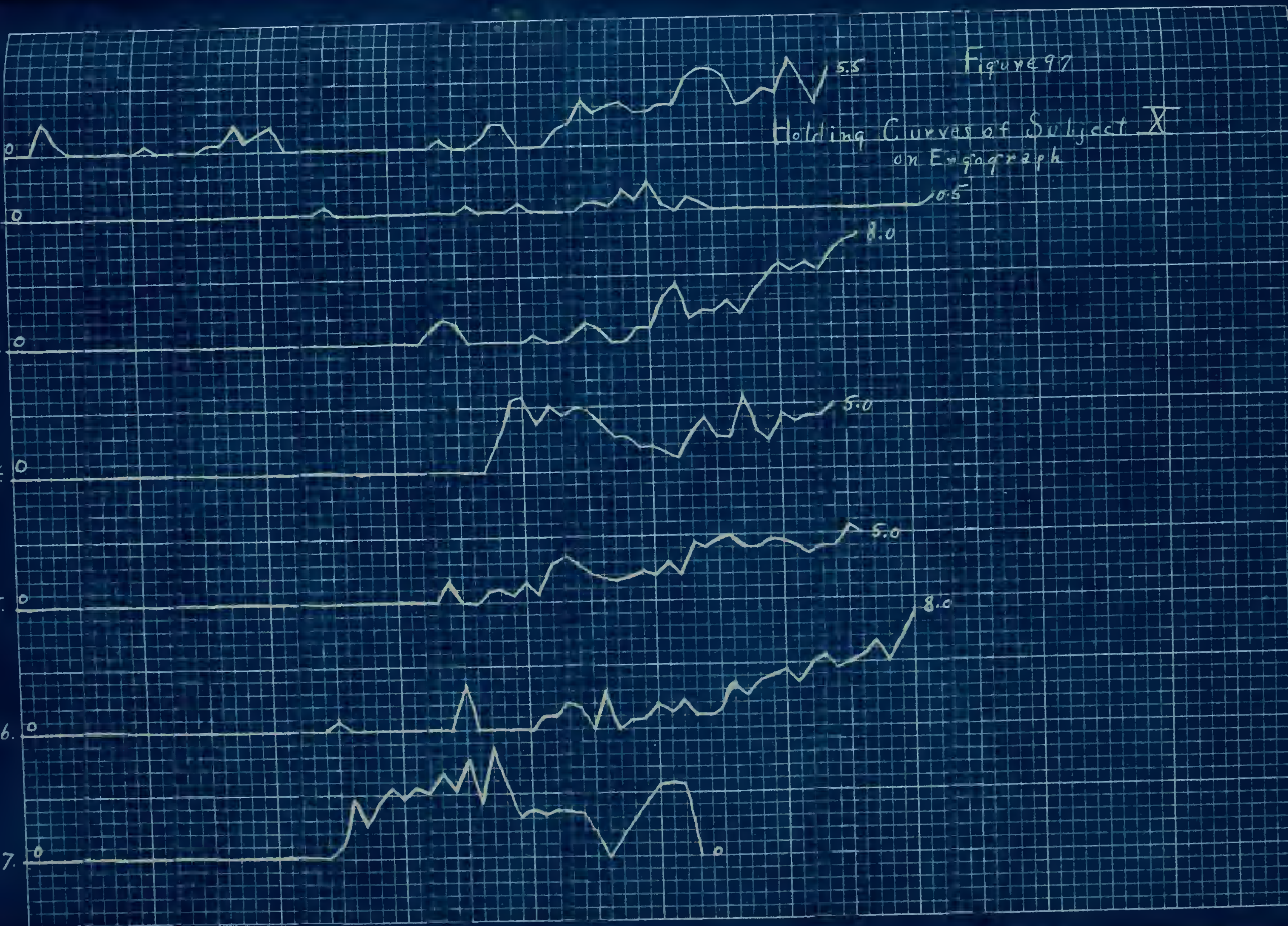


Figure 98

Holding Curves of Subject XI
on Ergograph

(No Holding in Curves 3, 7, + 8)

B. GENERAL DISCUSSION OF FATIGUE CURVES RESULTING FROM WORK ON THE ERGOGRAPH.

A quick glance at the fatigue curves produced by work on the ergograph (Figures ~~22~~ 77 to 95) leaves one impressed by their apparent similarity. More careful scrutiny will, however, reveal quite definite individual differences between subjects. For example, the steady decline from an initial maximum contraction is common to Subject VII (Figures 81 and 82) alone. Subject X (Figures 83 and 84) again shows his characteristic initial drop even as he did in the dynamometer curves. Subject XV (Figure 90) has a characterisitic early high level of performance peculiar to her curves alone. It is true, however, that in some cases it is hard to distinguish between the curves of two individuals, so much alike are their general contours. Subject XXII (Figure 95) on the other hand runs true to form. Hardly a single curve bears a resemblence to its neighbor.

The curves upon the ergograph seem little influenced by change in time of day, however, as Table VIII, page 205, illustrates. There is a tendency for the morning curves of a given individual to be similar to each other. A similar tendency was noticed in the dynamometer study. The afternoon curves taken on the ergograph also tend to be similar to each other for any given subject. This is just the reverse of what was true about the afternoon curves taken on the dynamometer. Also, the ergographic curves show no tendency to group into morning and afternoon categories. The curves for the majority of the individuals tend to be the same regardless of time of day. Only three subjects show anything akin to time groupings. The effect of food intake upon the curves cannot be definitely stated. Only

TABLE VIII.

The Effect of Time of Day Upon the Fatigue Curves Taken on the Ergograph.

| Subject | Morning Curves Similar | Morning Curves Different | Afternoon Curves Similar | Afternoon Curves Different | Curves Grouped into a.m. & p.m. | Curves Not Grouped |
|---|---|---|---|---|---|---|
| I. | X | | X | | | X |
| II. | X | | X | | | X |
| VI. | X | | X | | | X |
| VII. | X | | X (noon curve) | | | X |
| X. | X | | X | | | X |
| XI. | X | | | X | X | |
| XII. | | X | | X | | X |
| XIV. | X | | X (noon 1) | | | X |
| XV. | X | | X | | X | |
| XVI. | X | | X | | | X |
| XVII. | X | | X | | | X |
| XVIII. | X | | X | | X | |
| XXII. | | X | | X | | X |

in three instances did any subjects come in for a record just after eating. Subjects VI (Figure 80, 4), VII (Figure 82, 6) and XIV (Figure 89, 5), all have one afterdinner curve. In each case it is the shortest curve of the group. It is weaker in the case of Subject VI and shows a rapid dropping-off in the case of Subject XIV. From what has been said about the effect of food intake upon the fatigue curves in the dynamometer study, these conditions are about what one would expect. There is not enough evidence to draw a definite conclusion, however.

The most important factor influencing the fatigue curve, is still the type of activity previous to recording. Table IX, page 207, indicates the number of curves studied under each factor, and the number of curves thus influenced. It will be seen that of the 93 curves studied, 69 were influenced by some form of mental or physical task other than food intake. Table X, page 208, lists the influences of the various factors upon the curves studied relative to each factor and upon the entire group. It will be seen from Table X that 74.1% of the curves are affected by some mental or physical task prior to recording. Eating influences another 3.2% so that 22.7% of variation is left to be attributed to other factors.

One of these factors no doubt is lack of sleep. Curve 5 of Subject XII was taken after only 3 hours of sleep the night before. The curve is quite short and weak. The subject had been resting previous to taking the record. Subject XVI (1 and 4, Figure 91) estimated her strength as very low after 4 hours of sleep before taking a record in the morning. Curve 1

TABLE IX.

Number of Curves Influenced by Previous Activity for Group Working on Ergograph.

| | Column 1. Number of Curves Taken After Different Kinds of Work. | | | | Column 2. Number of Curves Influenced by Activity. | | | |
|---|---|---|---|---|---|---|---|---|
| Subj. | Gen. Ment. | Int. Ment. | Light Phys. | Hard Phys. | Gen. Ment. | Int. Ment. | Light Phys. | Hard Phys. |
| I. | 3 | | 2 | 1 | 3 | | 2 | 1 |
| II. | 9 | | | | 8 | | | |
| VI. | 3 | | 2 | 1 | 3 | | 0 | 1 |
| VII. | 6 | | 1 | | 4 | 0 | | |
| X. | 3 | | 4 | | 2 | | 3 | |
| XI. | 5 | | 3 | | 3 | | 3 | |
| XII. | 6 | 1 | 1 | | 6 | 1 | 1 | |
| XIV. | 5 | | | 1 | 3 | | | 1 |
| XV. | 6 | | | | 6 | | | |
| XVI. | 7 | | | | 5 | | | |
| XVII. | 7 | | | | 6 | | | |
| XVIII. | 7 | | | | 6 | | | |
| XXII. | 5 | | 1 | | 0 | | 1 | |
| Curves studied per Activity / Curves Influenced per Activ. | 72 | 1 | 14 | 3 | 55 | 1 | 10 | 3 |

Total No. of Curves after Mental and Physical work....90

No. Curves After Eating......3

Total Curves................93

Total No. Influenced by Mental and Physical work...69

No. Influenced by Eating....3

TABLE X.

Comparison of Factors Influencing the Fatigue Curves Taken on the Ergograph.

| Factors | No. of Curves Studied Relative to Each Factor | No. of Curves Influenced by Each Factor | % of Curves Studied Influenced by Each Factor | % of all Curves Influenced by Each Factor |
|---|---|---|---|---|
| General Mental Work | 72 | 55 | 76.3 | 59.1 |
| Intense Mental Work | 1 | 1 | 100 | 1.07 |
| Light Physical Work | 14 | 10 | 71.3 | 10.7 |
| Hard Physical Work | 3 | 3 | 100 | 3.2 |
| Total Mental and Physical work | 90 | 69 | 76.6 | 74.1 |
| Eating | 3 | 3 | 100 | 3.2 |
| | 93 | 72 | | 77.3 |
| Other Factors... | | 21 | | 22.7 |

resulted quite weak but of average length. That afternoon , after a five hour interval between work periods, she again made a record. Curve 4 was the result--similar to the morning curve but much weaker and shorter in length. Evidently two curves taken in one day after only four hours of sleep the night before has a decided effect upon curtailing production in the second curve. In the case of Subject XVIII who had spent a sleepless night because of insomnia, lack of sleep matters little. His production is quite normal. One cannot be expected to draw much in the way of conclusions from such conflicting data. It is enough to simply indicate that sleep is one of the uncountable little variances in the daily routine which may have effect upon changing the nature of the fatigue curve.

The condition of one's health will assert another influence upon the curve. Subject XXII (Figure 95) complained of a head cold and feverish condition prior to one of her recordings. Curve 1 which resulted is much more irregular than her other curves.

The emotional tension after an examination period seems to have the same influence upon the ergograph curves of fatigue as it did for the dynamometer curves so affected. A high level of work is maintained for a brief period, and then the curve drops readily. It is very irregular and may be one of largest in the group. Subject XII (8, Figure 87) illustrates the single case appearing in the ergographic study under these conditions.

The data relative to the influence of subjective estimate of strength upon changing the fatigue curve is quite indefinite on the whole, less people are able to make an estimate which will conform with their production. From previous work by other investigators upon the topic of subjective estimates and correlation with performance, this negative relationship is what one would expect. The fact that so many subjects were able to estimate correctly in the dynamometer study while so few seem to judge correctly here may be attributed to several factors. In the first place, the present group consists of only thirteen out of the twenty-two. Some of the good guesses are thus automatically eliminated. At the same time, the type of activity is changed. Finger-pulling against a spring is not as tiring as gripping a dynamometer where larger muscle groups in play afford one abasis for future estimates.

Warming-up is far more common in the fatigue curves for the ergograph than was the case for the dynamometer. Very few subjects do not exhibit the phenomenon. Initial spurt , however, is represented by only one subject, X, who exhibited the phenomenon as his chief characteristic on the dynamometer as well. End spurt is likewise not as common in these curves as in the other study. Subjects X, XIV, and XVIII indicate this trend most predominantly.

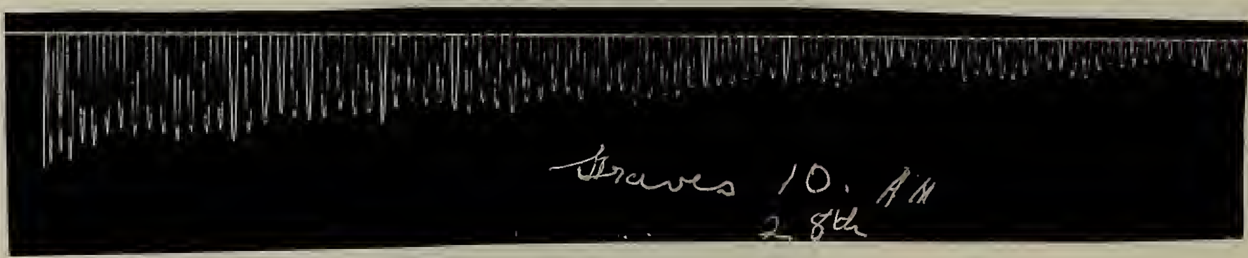
One curve in particular is of interest. Curve 9 of Subject VII (Figure 82) begins much higher than his others, but it is so steep and distinctly different from his other curves, that one wonders what prompted such performance. Just as the subject was ready to take his record, another instructor brought a group of thirty visiting high school students into the laboratory. Naturally interest was keen about the particular set-up of the apparatus. Subject VII took his record in the presence of the group. It is evident that he reached his highest maximum contraction first, had a short initial spurt, recovered a bit but then dropped off rapidly and abruptly. It was quite evident that the presence of the group caused him to pull harder at each beat than usual so that fatigue was more rapid. In this case the presence of a large audience certainly influenced the nature of the fatigue curve.

Subject XVII (Figure 92) also presents an interesting study. In no instance do her curves show complete fatigue. Each end point indicates the lowest level the subject reached before she could carry-on indefinitely at a low level of contraction. Even with the kymograph drum running at as low a speed possible, the subject would work until her record had been traced clear around the drum. The subject claimed she was pulling her maximum each time. One explanation for these abnormally long records without complete exhaustion is that even a pull of once every half second on the ergograph allows too much chance for recuperation between pulls, in the case of this subject at least. Since the muscles involved are a small group compared with those involved in gripping the dynamometer, fatigue is not so widespread, and the waste products are taken care of readily by the circulatory system. This subject is the only one, with the exception of the boy, to produce very feeble records on the dynamometer. In many instances her records on the dynamometer are the shortest and weakest of the group. In spite of the fact that she does not exhaust readily and produces an abnormally long record on the ergograph, again her contractions at their strongest are relatively feeble when compared with most of the subjects.

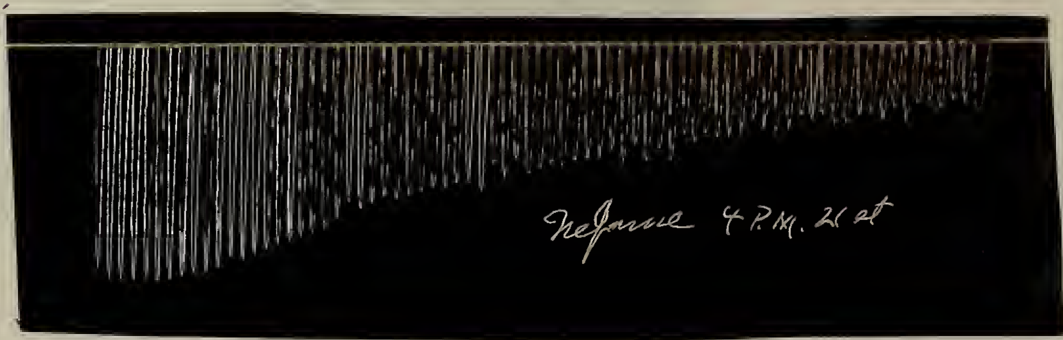
Holding on the ergograph is exhibited by only three subjects throughout the second study period. During the practice period preceding the actual gathering of data on the ergograph, every subject held to some degree. The instructions to relax between each pull were stressed during the practice period with the result that all but three of the thirteen produced records showing complete relaxation. Subject XI, one of the three who holds, likewise produced three curves during the study period which show complete relaxation. In the first study in which the dynamometer was used, no instructions were given relative to relaxation except in the case of Subject III whose abnormally high holding curves (Figures 13 and 14) have already been discussed. In his case it will be recalled, coaching greatly reduced the amount of holding. In this study on the ergograph, it seems fair to conclude again that, with conscious effort on the part of the subject, holding can be greatly reduced and even eliminated entirely. Subject I, X, and XI, however, could not seem to relax completely between pulls in spite of every effort to do so. Subjects I and X show holding curves (Figures 96 and 98) that are quite distinctly personal characteristics. Subject I holds for a few strokes in the beginning, relaxes entirely, and then holds more and more toward the end as he fatigues. Subject X usually has a long beginning period with no holding. Then he gets a "Warming period" (of which he was quite aware although he could never see his record being traced). During this so-called "warming period", the subject begins to hold slightly, but he makes an effort to overcome it. His efforts stem the holding somewhat, but the effect does not last long before he begins to hold more and more until he is exhausted. Interesting, too, is the fact that both of these subjects who produce consistent holding curves likewise produce correspondingly consistent fatigue curves. The holding of Subject XI is erratic. He can also produce a record at odd intervals showing complete relaxation. His fatigue curves on the ergograph are correspondingly inconsistent. A check upon the average holding curves of these subjects as they appear in Figures 100, 106, and 107, indicates that their holdings on the dynamometer and holdings upon the ergograph are decidedly unlike. In every instance, the holding upon the ergograph is much lower. The contours of the curves are quite unlike.

The study of what little holding there is upon the ergograph seems to emphasize again, however, some of the principles brought out in the dynamometer study. First, holding can be reduced by conscious effort, and second, if the holding curves are consistent for a given subject, his fatigue curves are likely to be consistent, and vice versa.

PLATE 13




A. A weak fatigue curve on the ergograph.




B. A strong but short fatigue curve
on the ergograph.

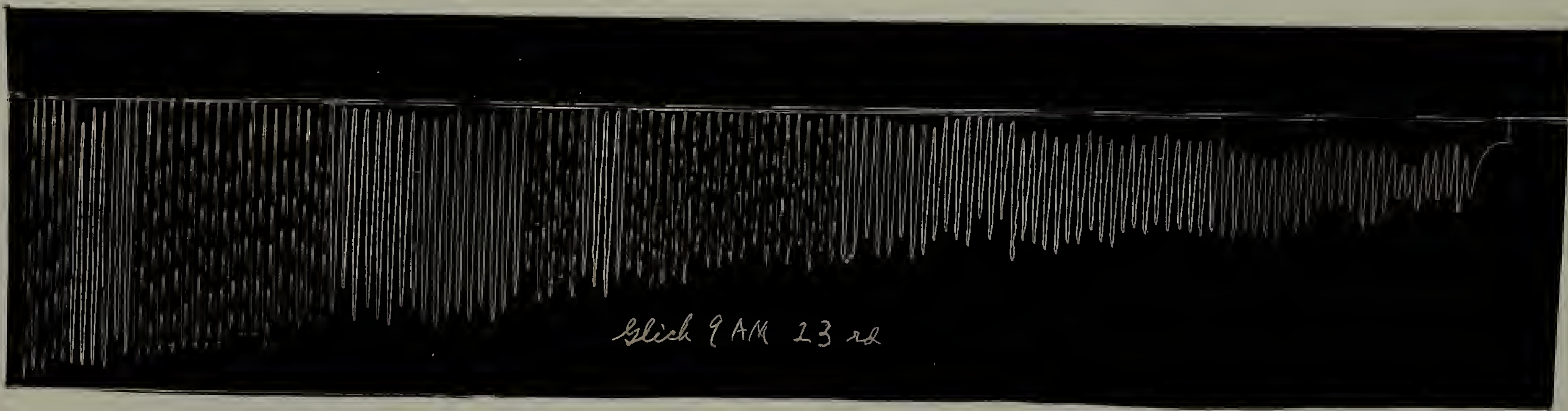



PLATE 14

Illustrating holding in an ergograph fatigue curve.

Figure 99

Average Curves of Subject I

Figure 100

Average Curves of Subject II

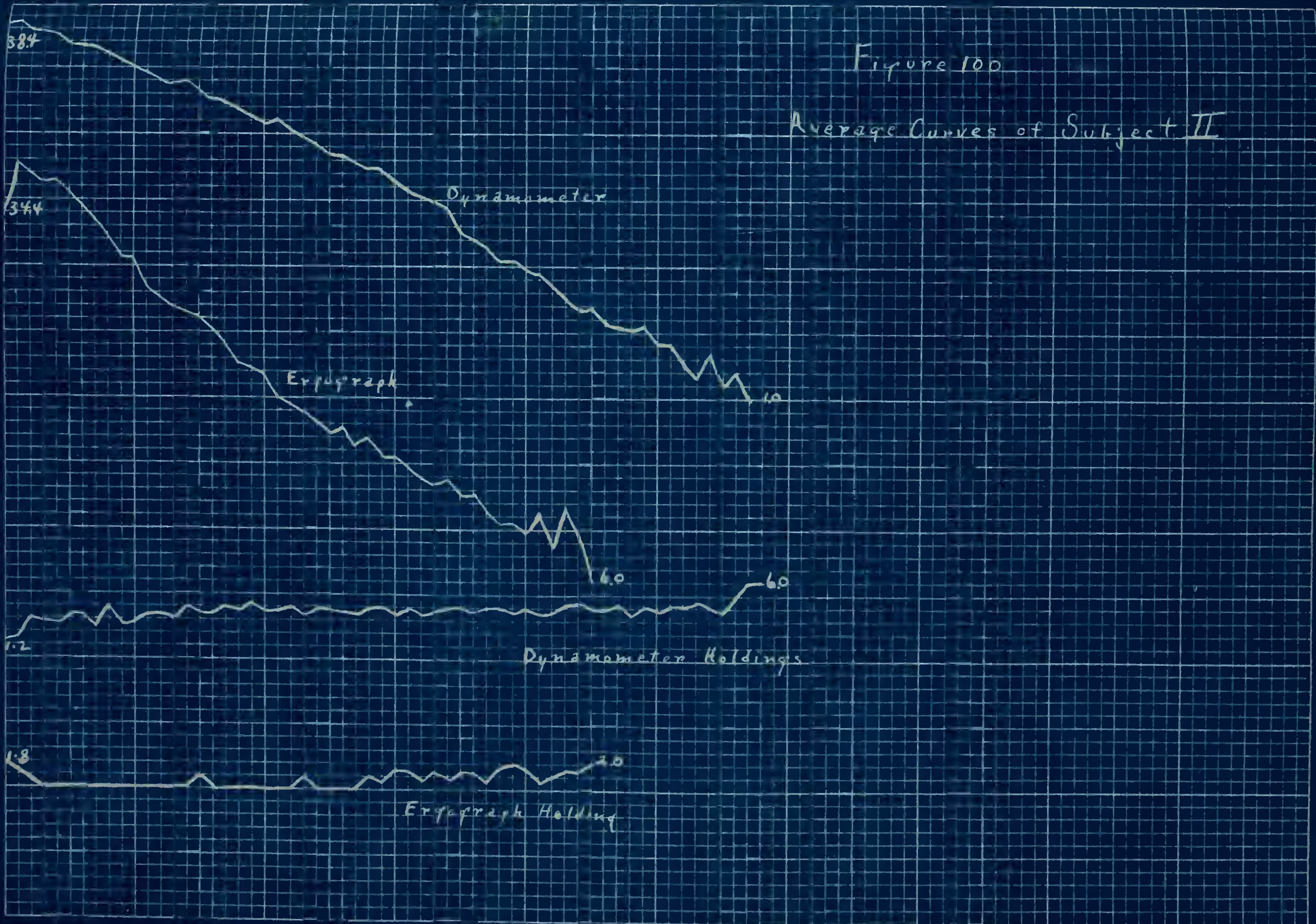
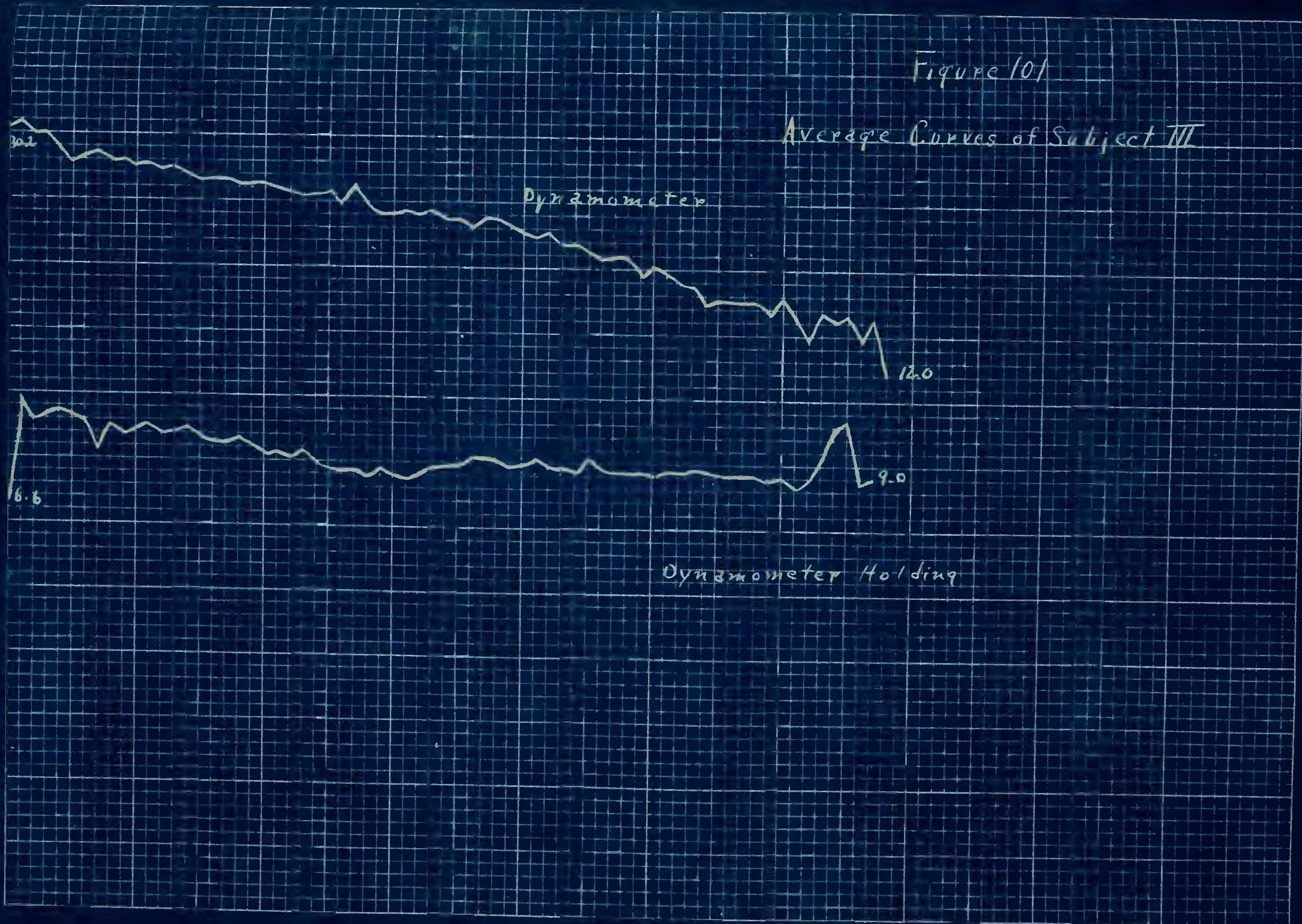


Figure 101

Average Curves of Subject VI



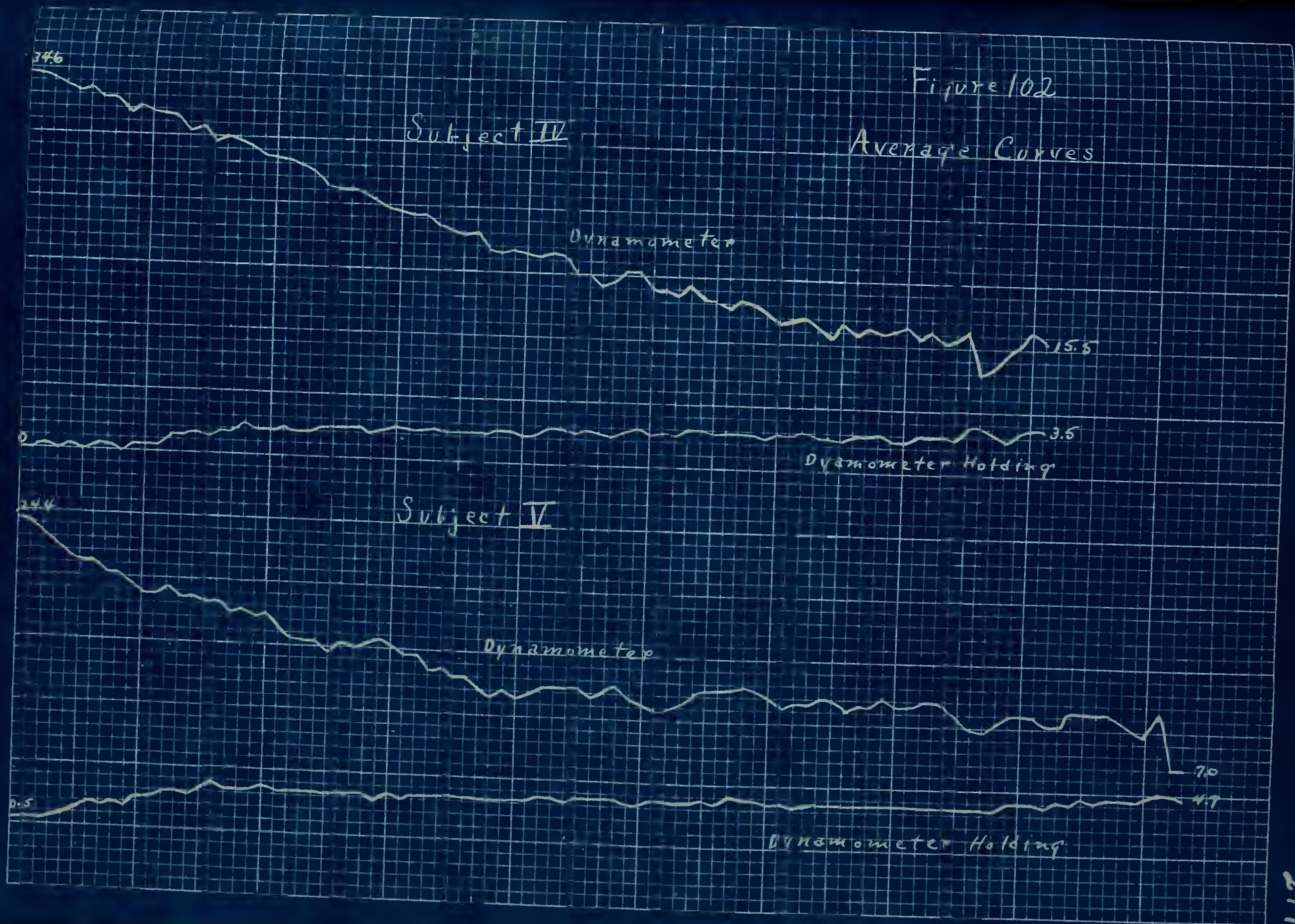


Figure 102
Average Curves
Subject IV
34.6
Dynamometer
15.5
0
3.5
Dynamometer Holding
Subject V
Dynamometer
7.0
0.5
Dynamometer Holding

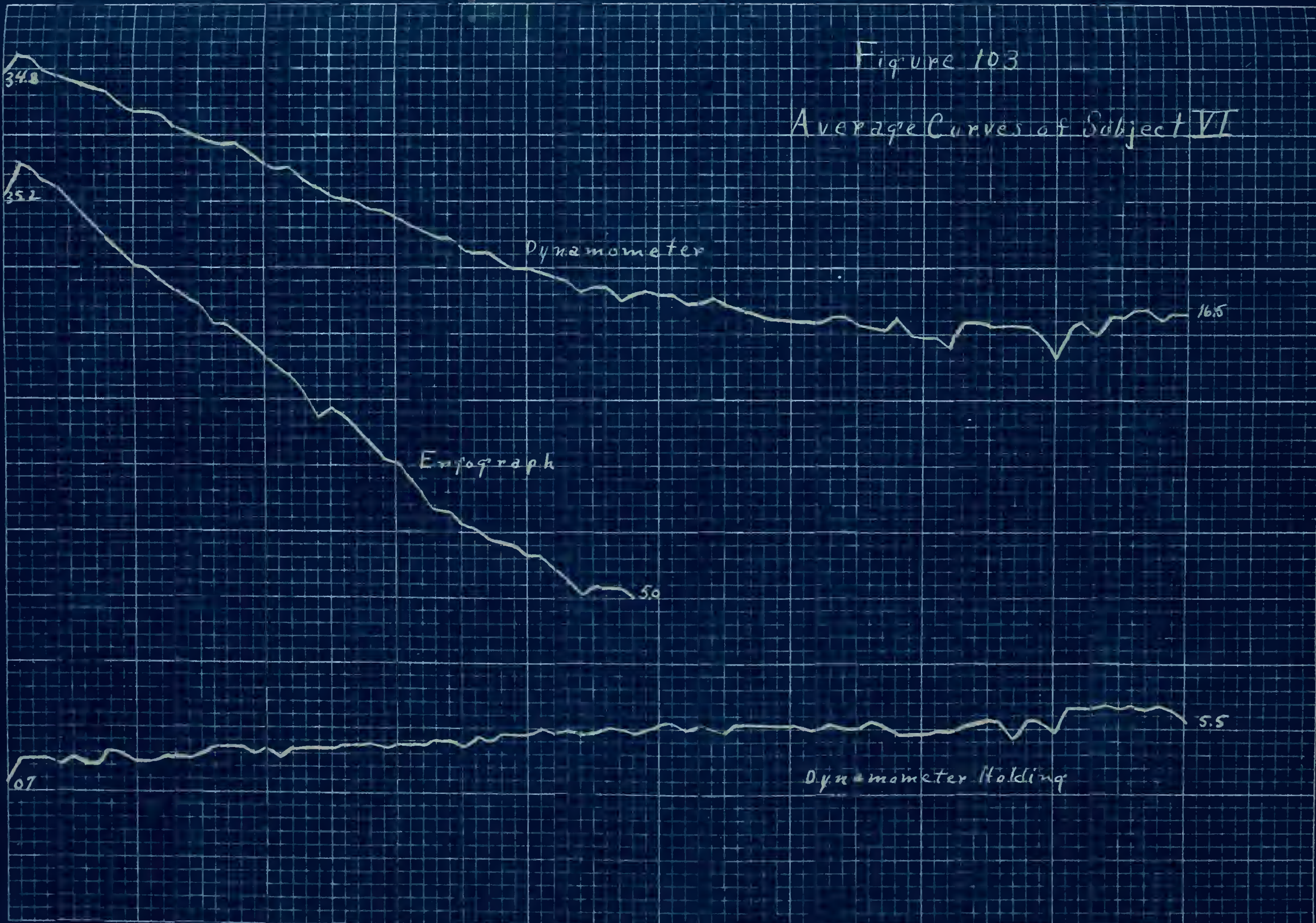



Figure 103
Average Curves of Subject VI

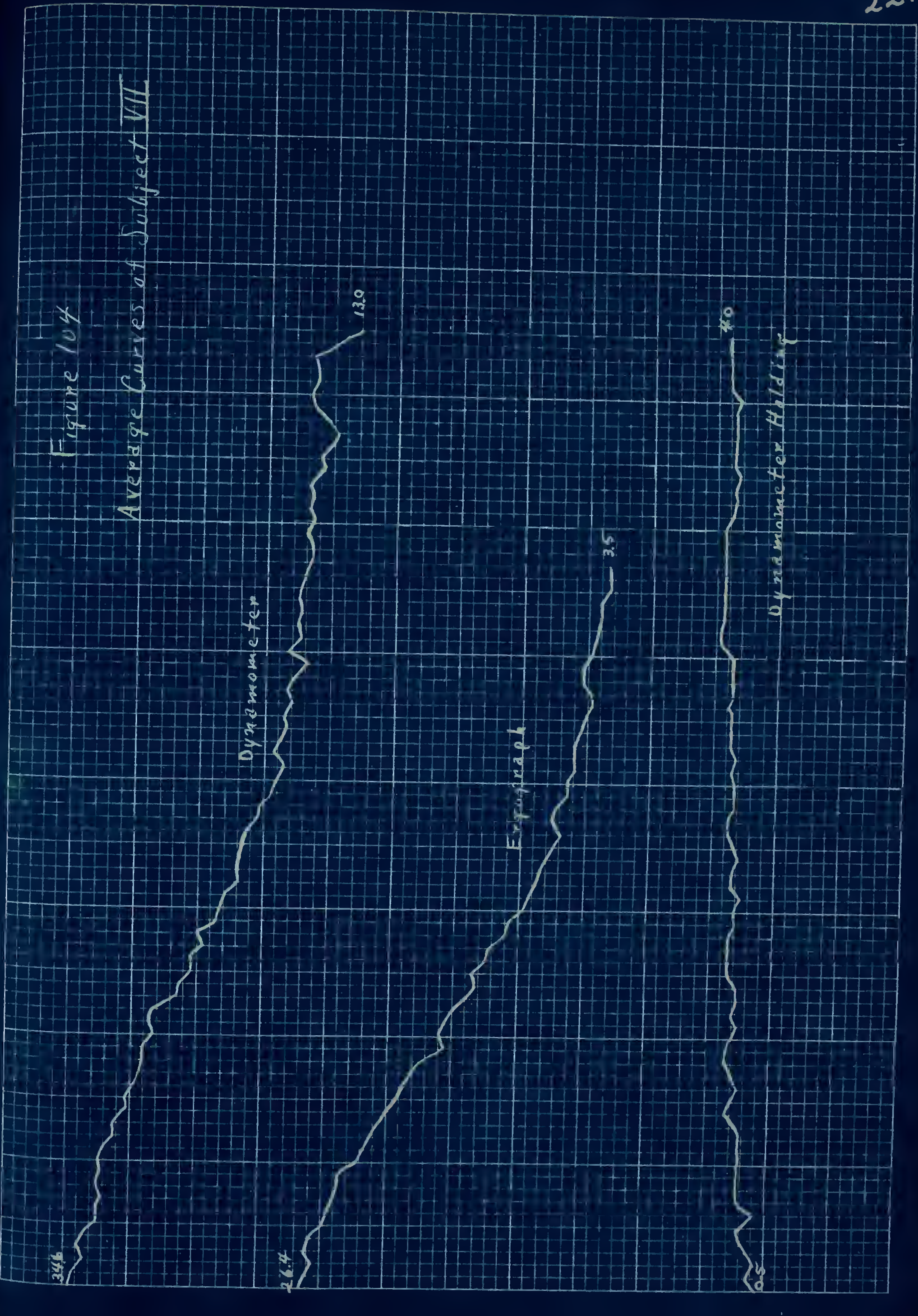



Figure 104
Average Curves of Subject VII

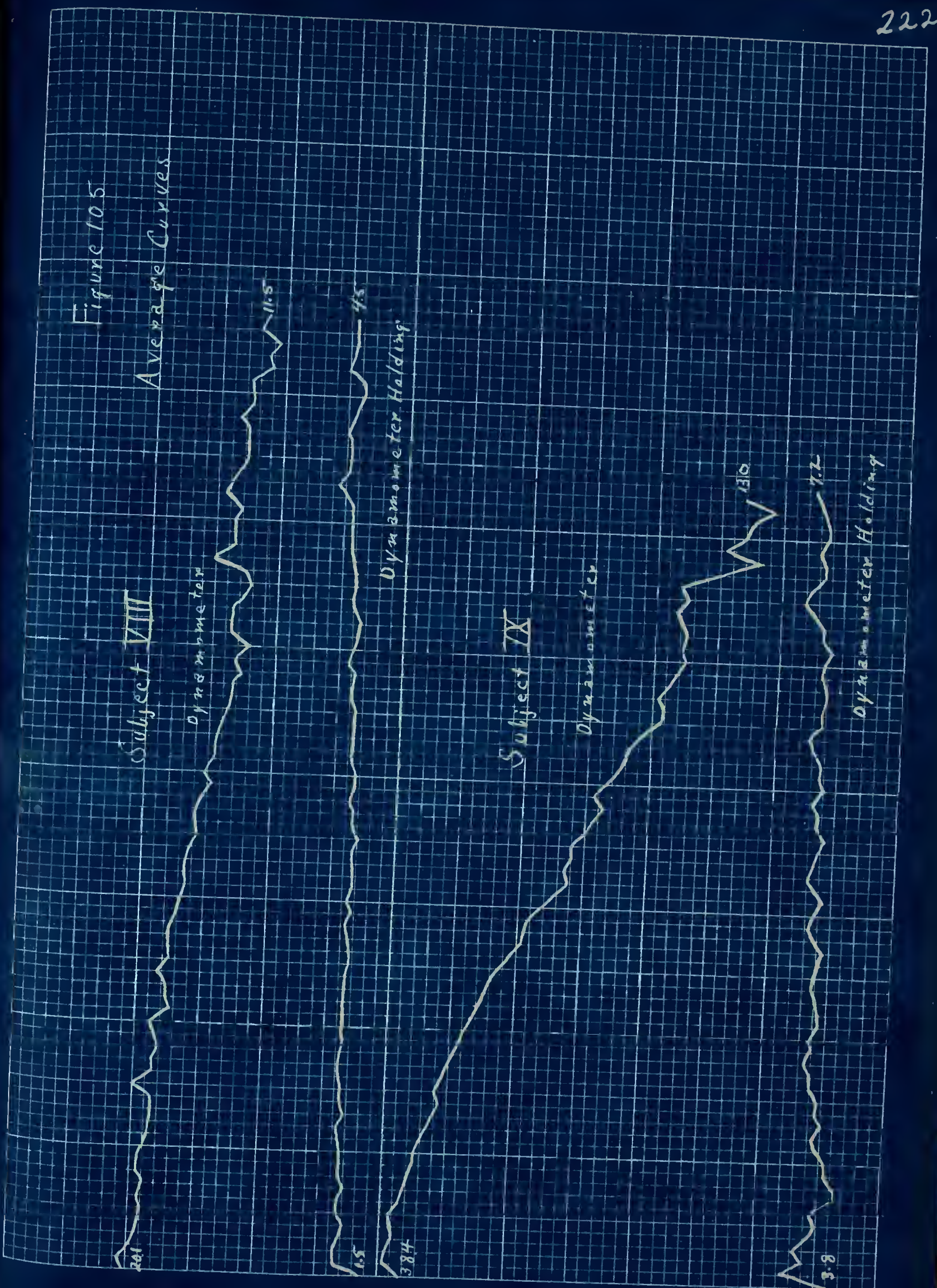


Figure 105
Average Curves
Subject VIII
Dynamometer
Dynamometer Holding
Subject IX
Dynamometer
Dynamometer Holding
201
11.5
1.5
3.84
130
3.8
7.2

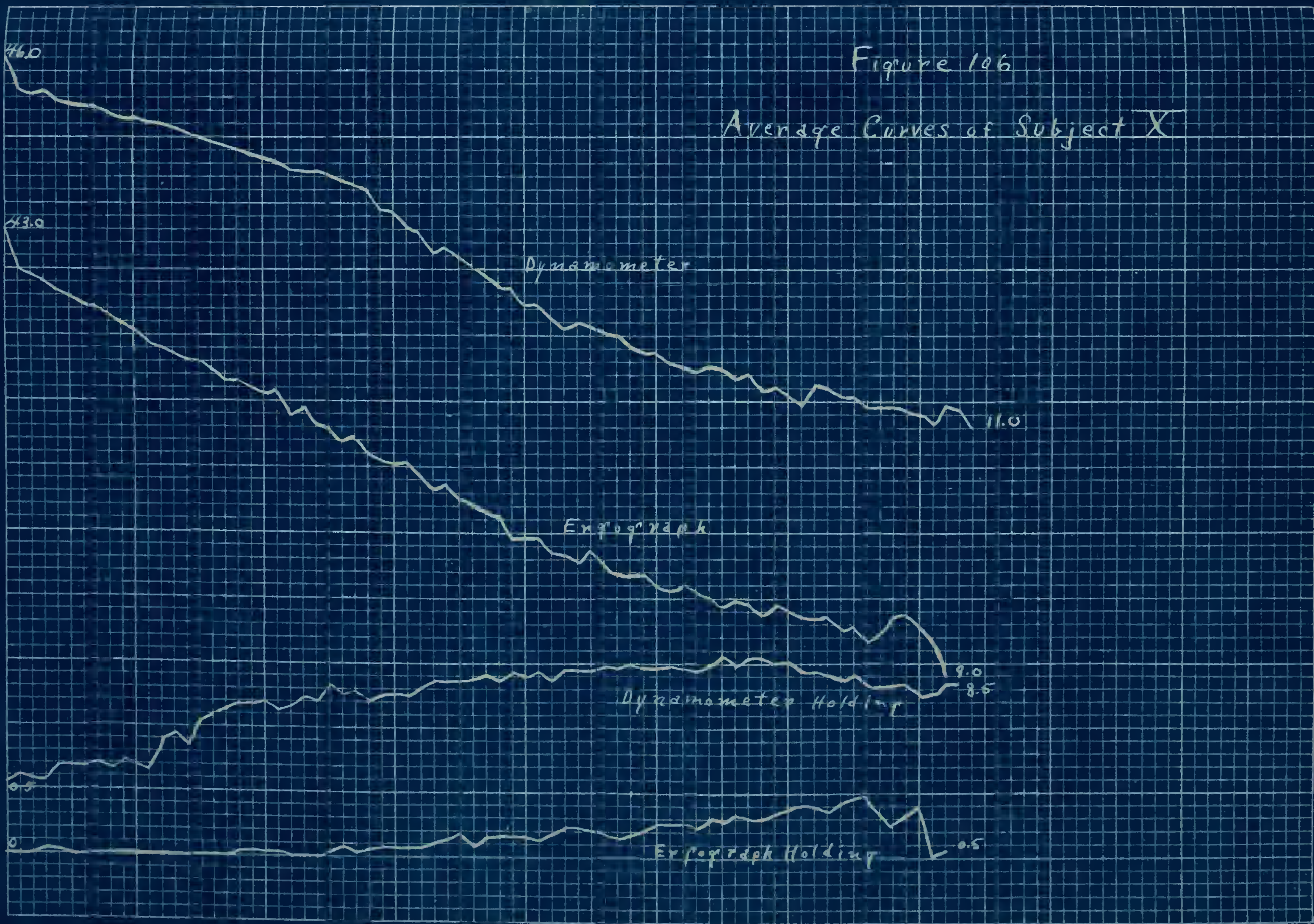


Figure 106
Average Curves of Subject X
46.0
43.0
Dynamometer
11.0
Ergograph
9.0
8.5
Dynamometer Holding
0.5
0
Ergograph Holding
0.5

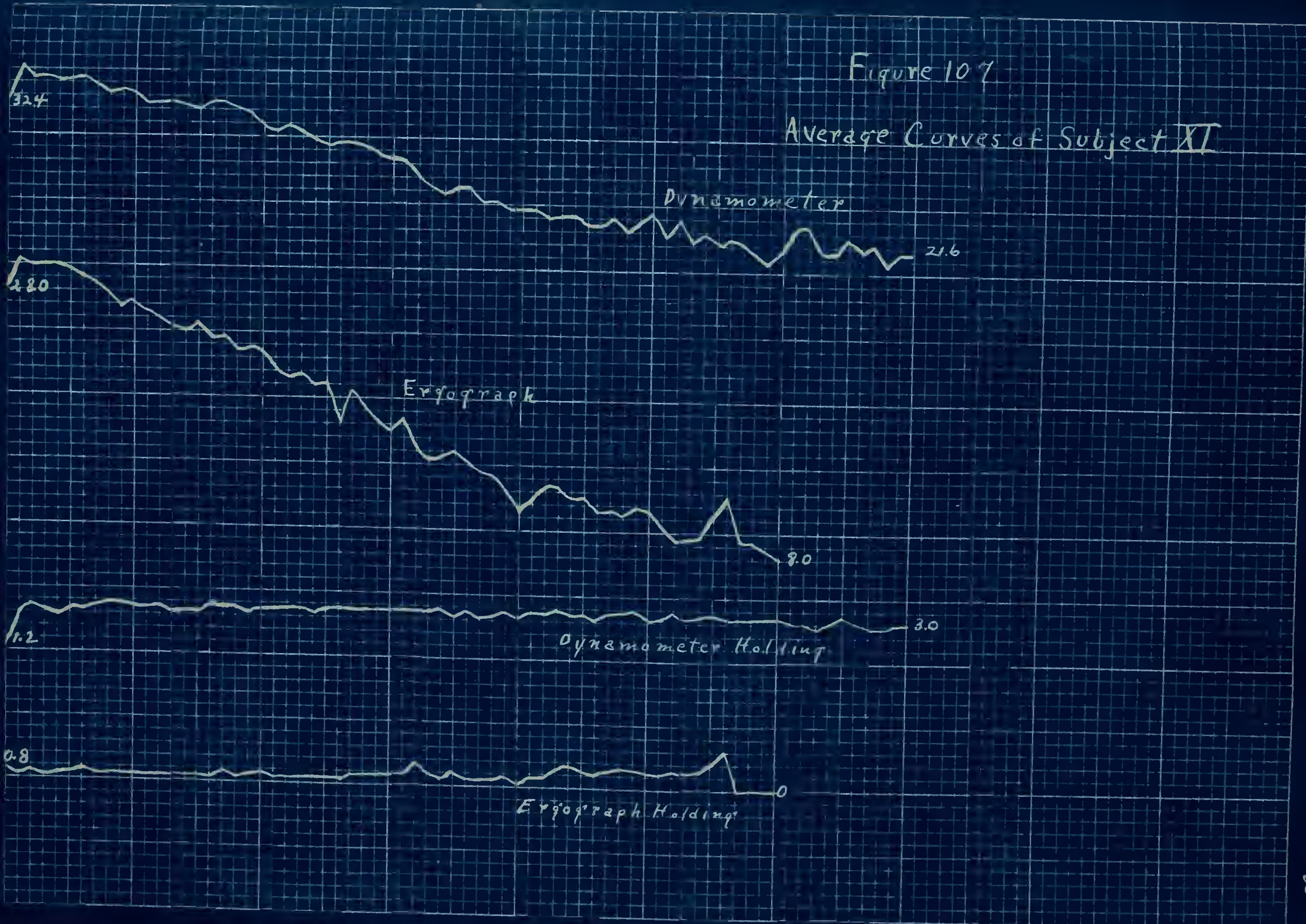



Figure 107

Average Curves of Subject XI

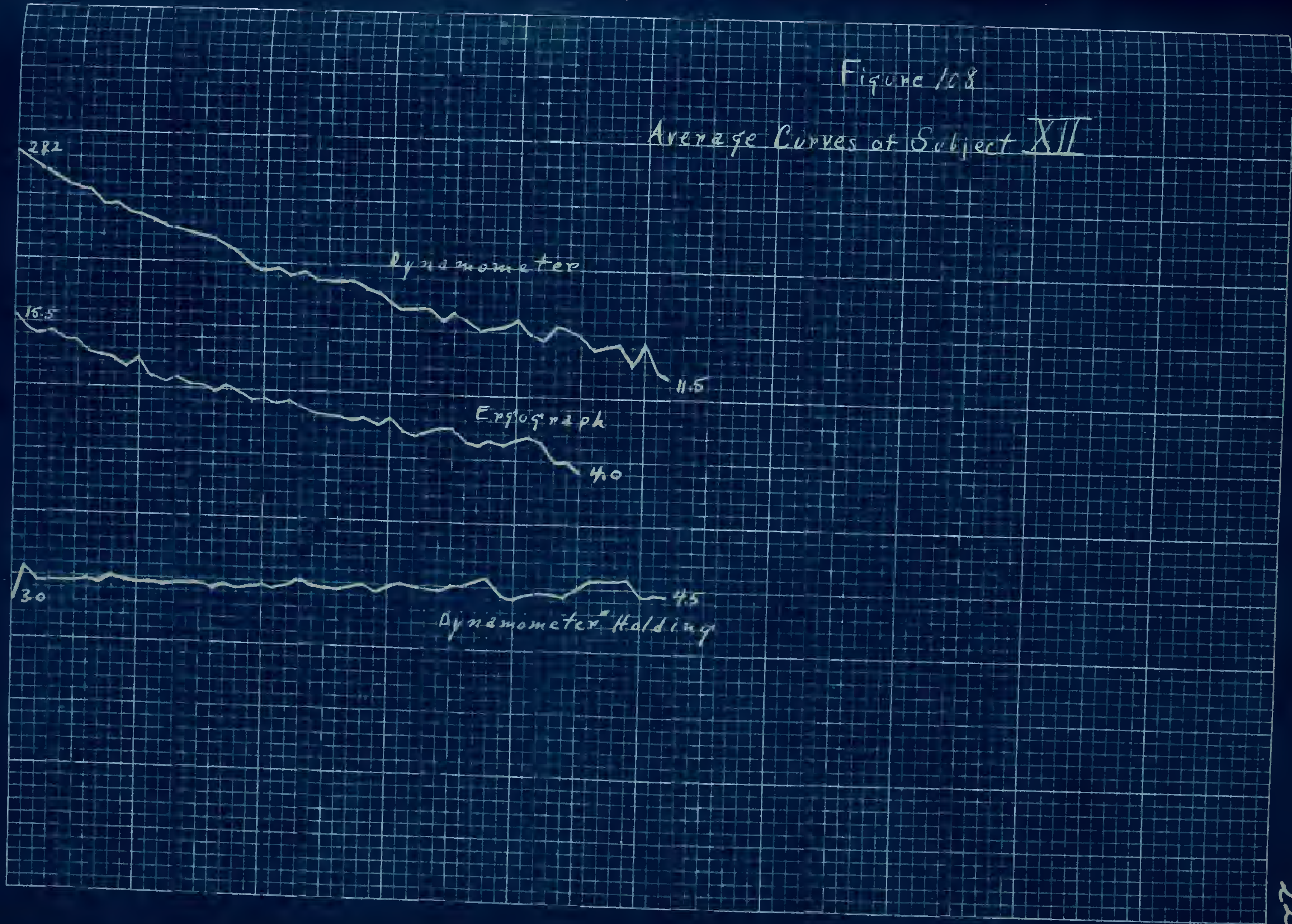


Figure 108
Average Curves of Subject XII
28.2
Dynamometer
11.5
15.5
Ergograph
4.0
3.0
4.5
Dynamometer "Holding"

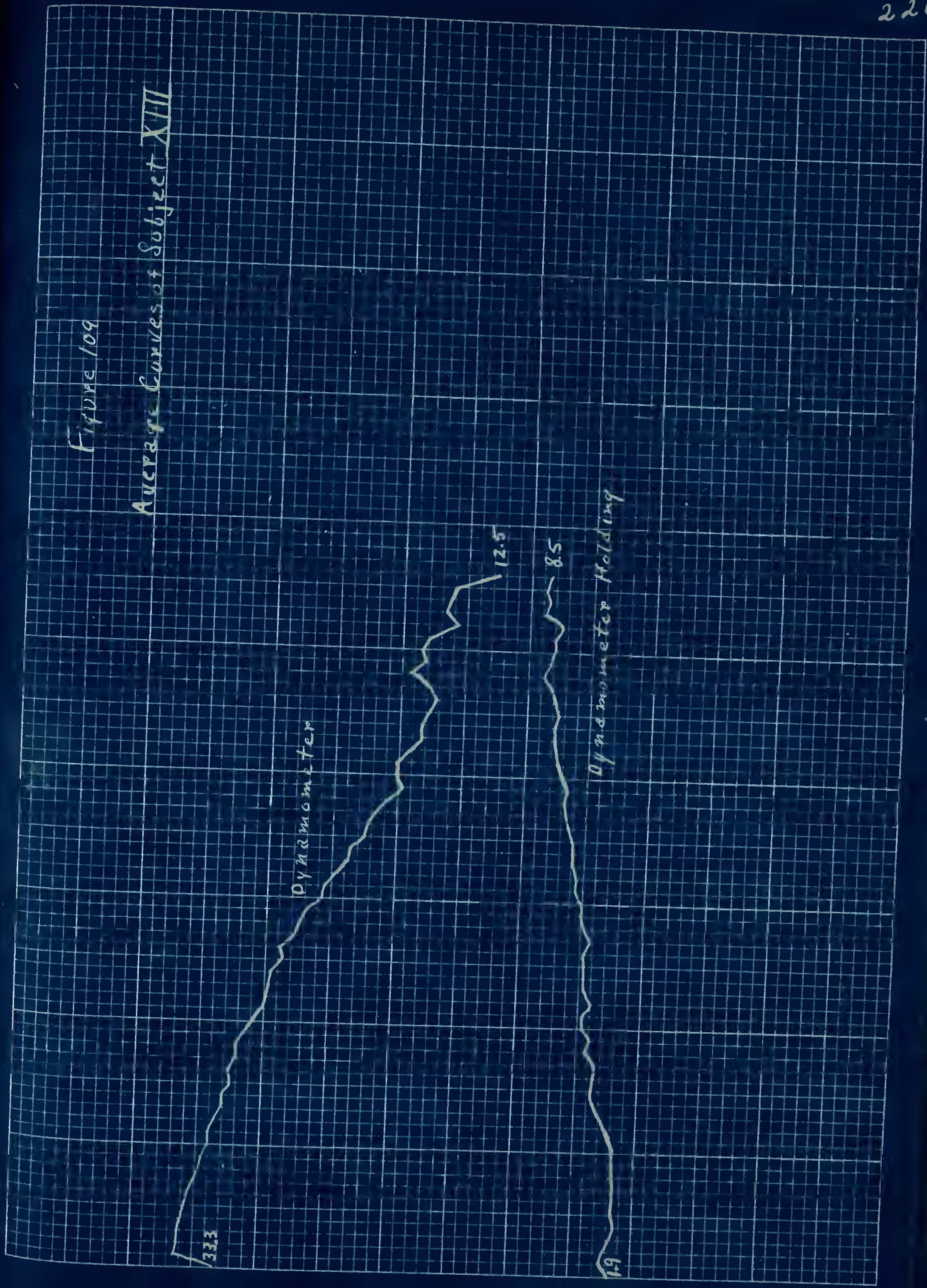


Figure 109
Average Curves of Subject XIII
Dynamometer
Dynamometer Holding
12.5
8.5
32.3

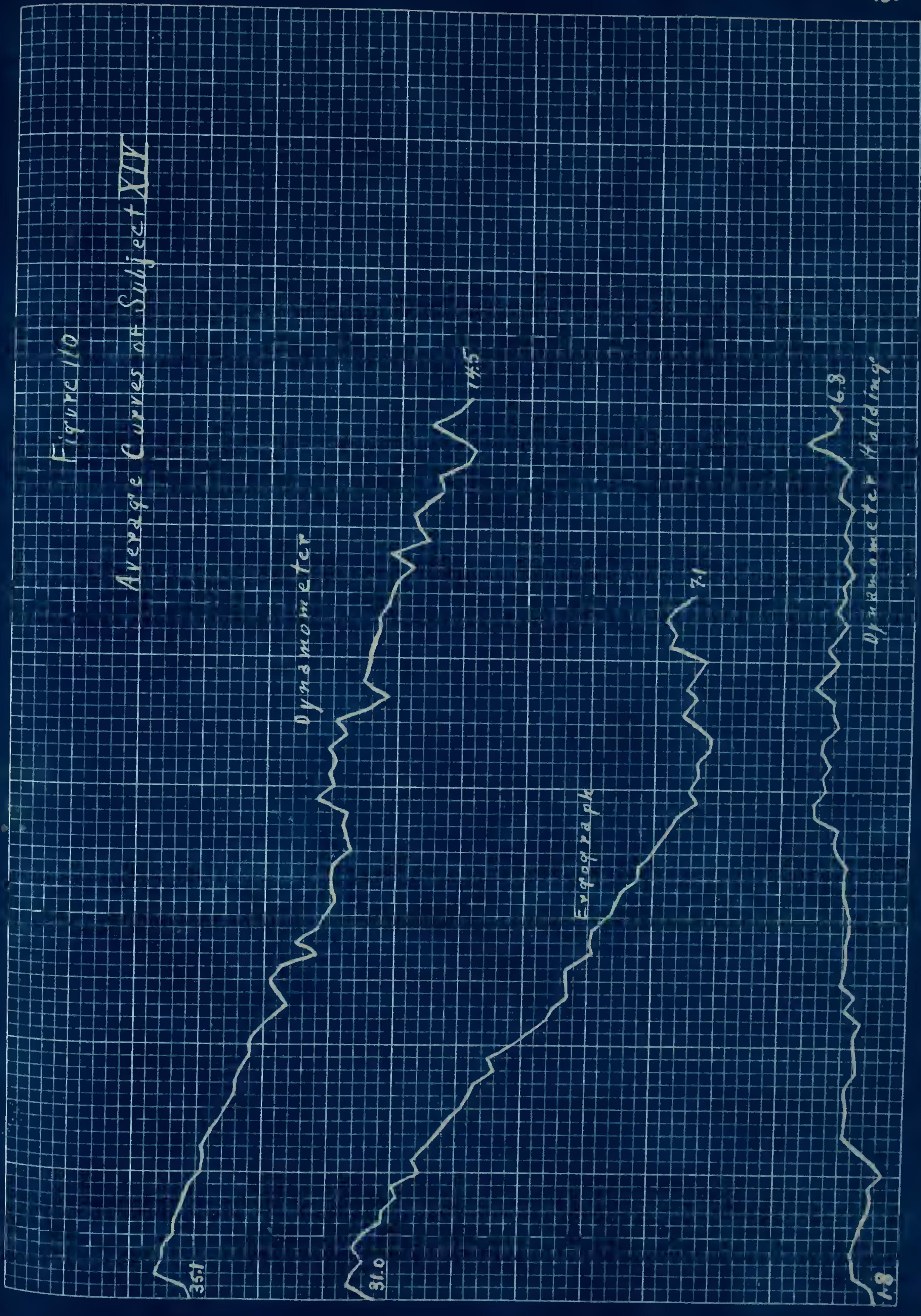



Figure 110
Average Curves of Subject XII

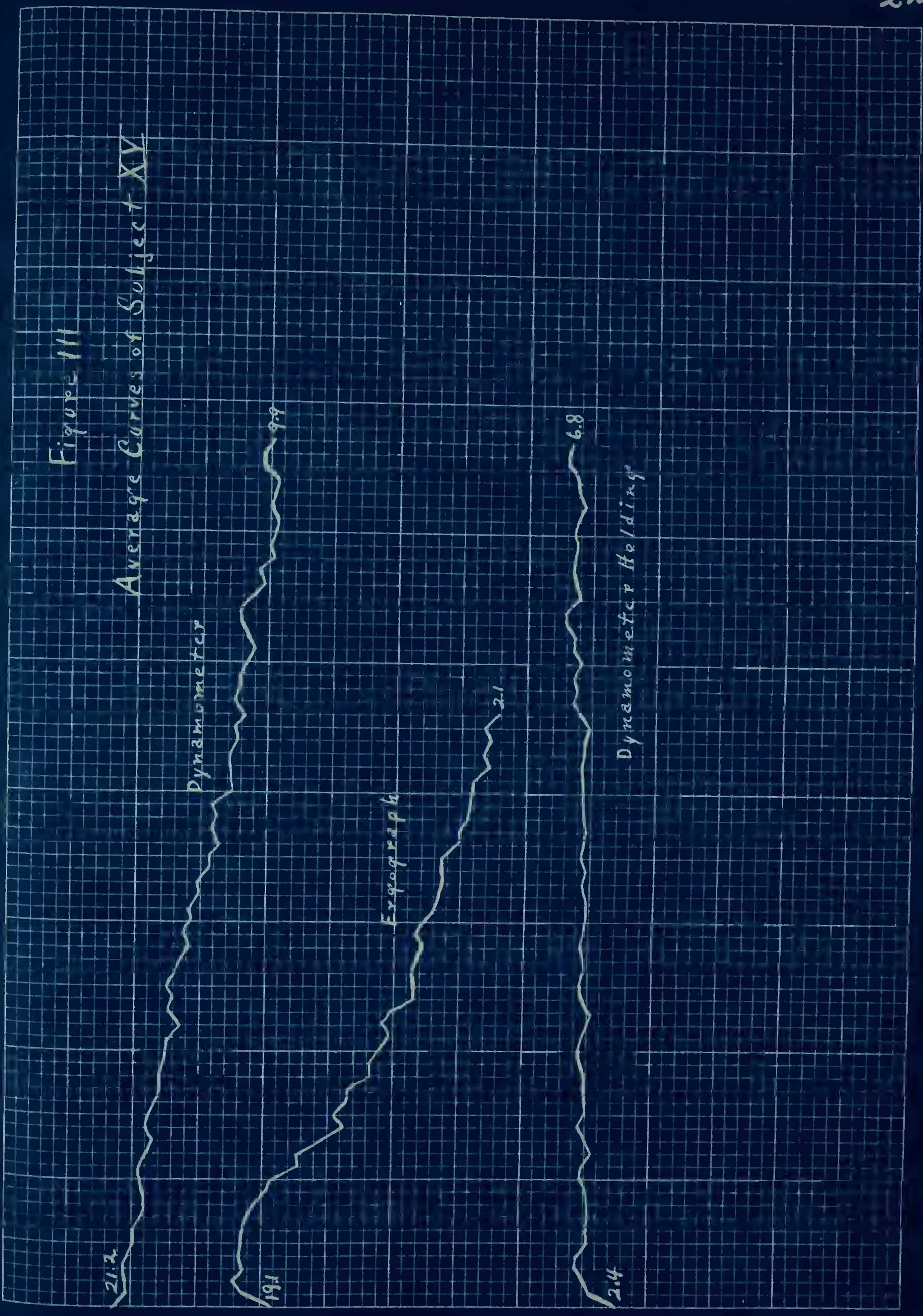
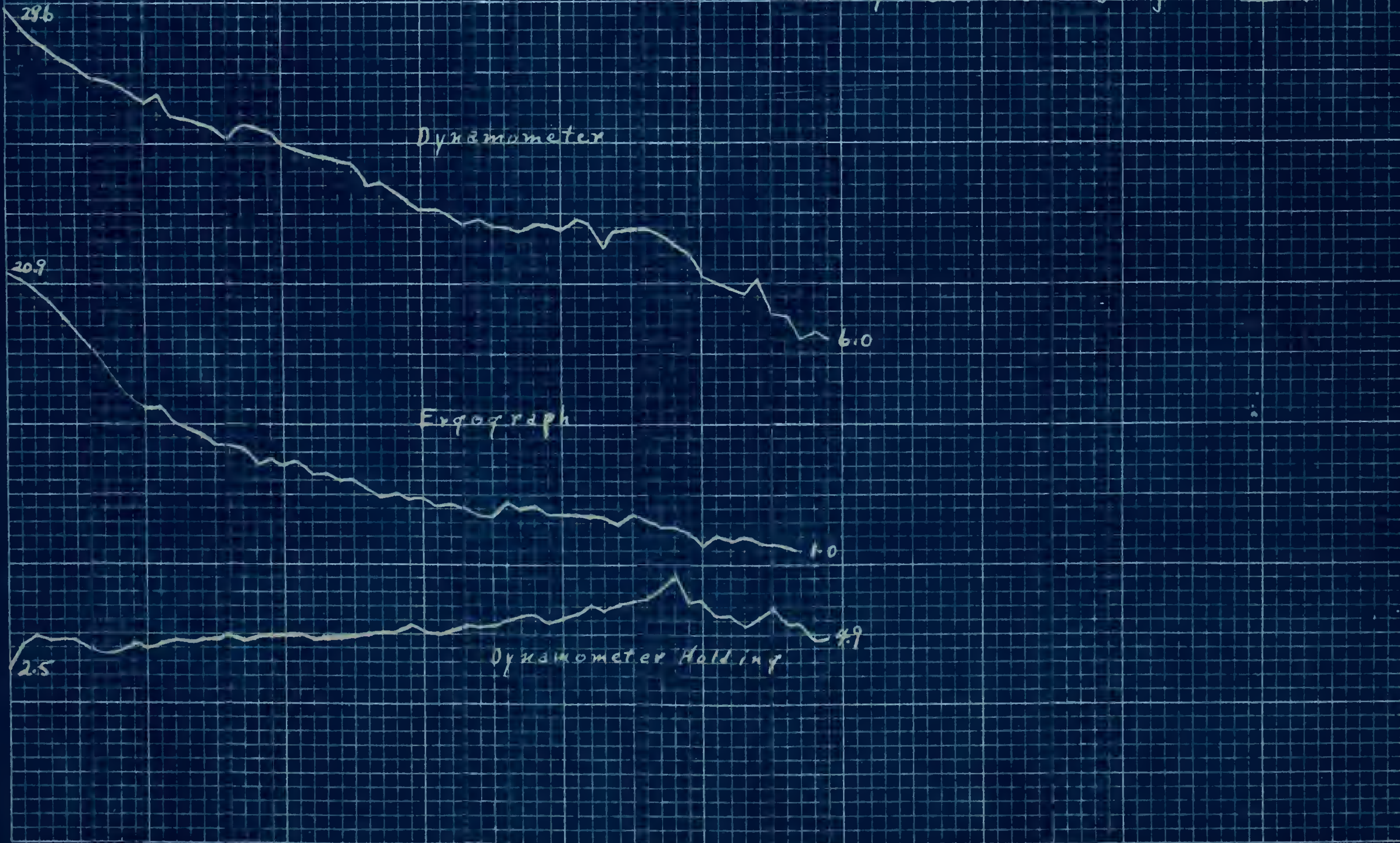


Figure III
Average Curves of Subject XV
Dynamometer
Ergograph
Dynamometer Holding
21.2
9.9
19.1
2.1
2.4
6.8

Figure 112

Average Curves of Subject XVI



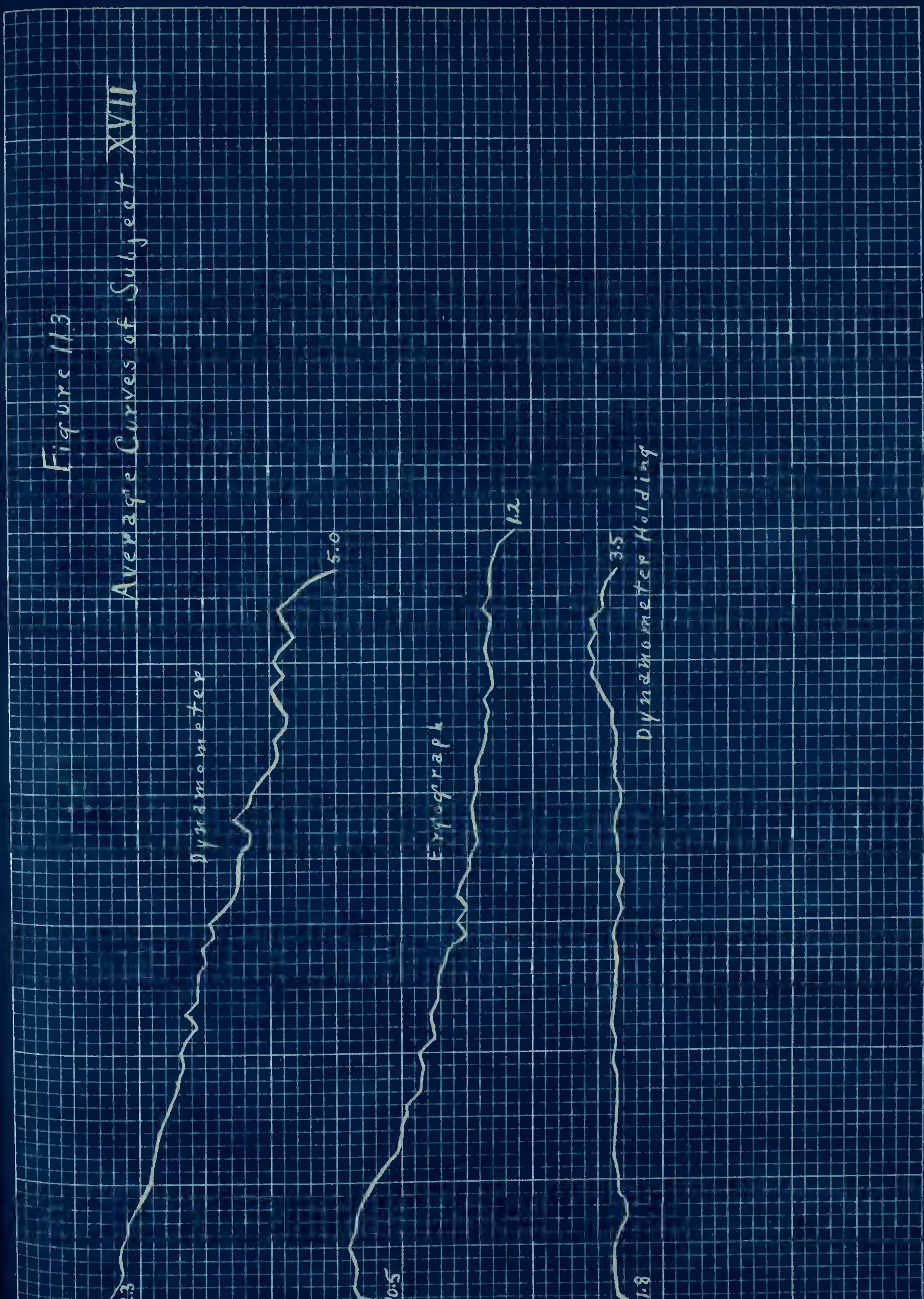
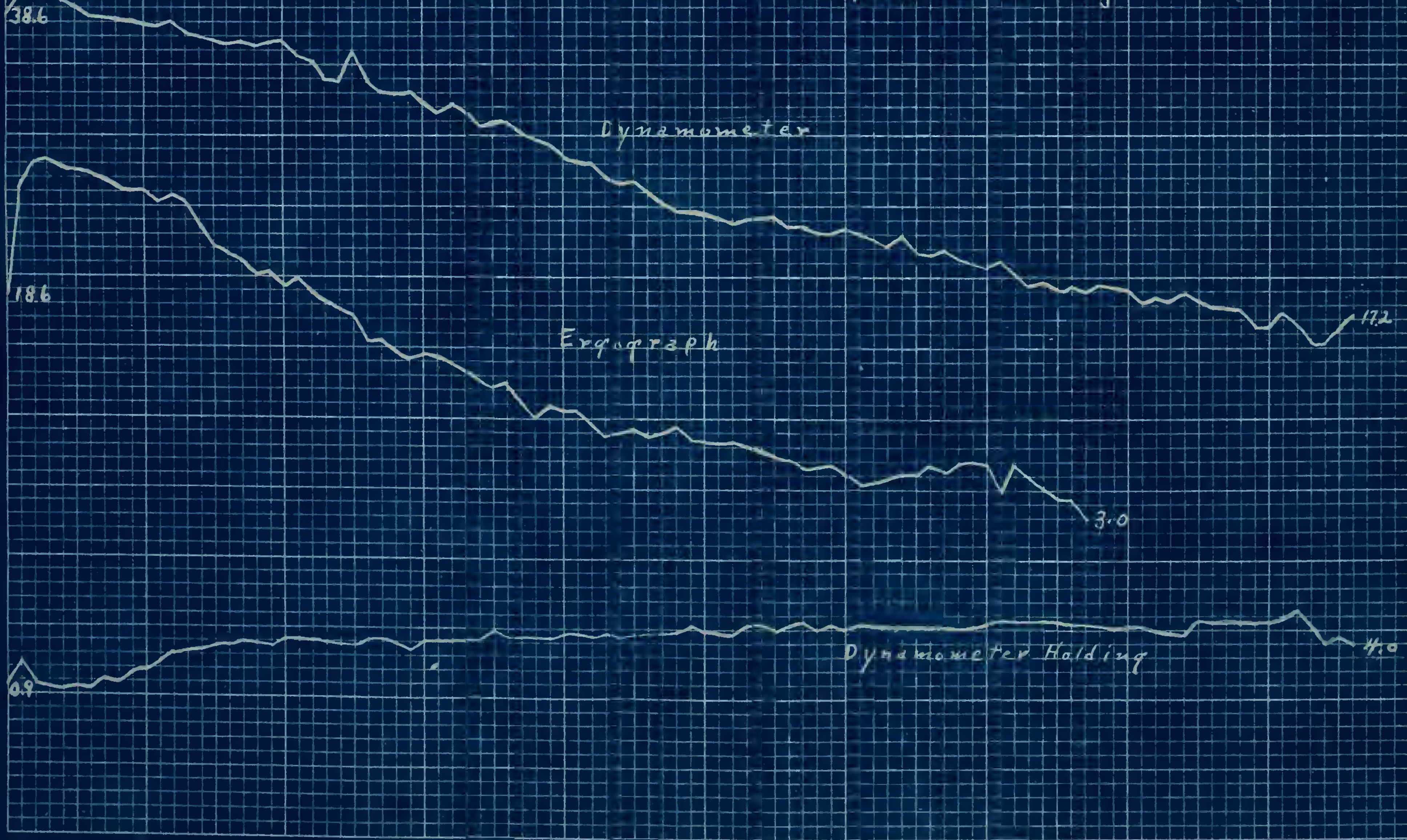


Figure 113
Average Curves of Subject XVII
Dynamometer
Ergograph
Dynamometer Holding
22.3
5.0
10.5
1.2
1.8
3.5

Figure 114

Average Curves of Subject XVIII



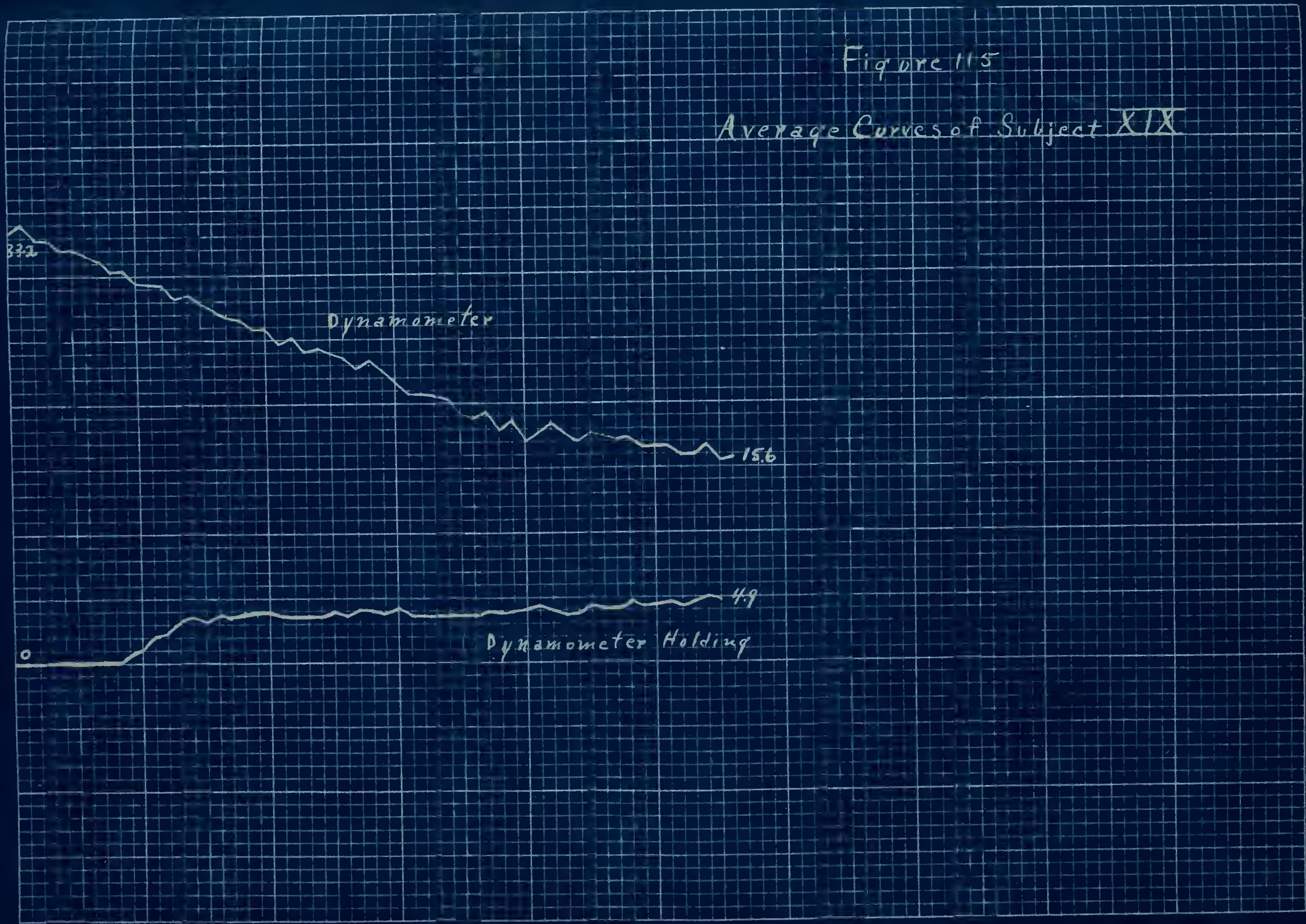



Figure 115

Average Curves of Subject XIX

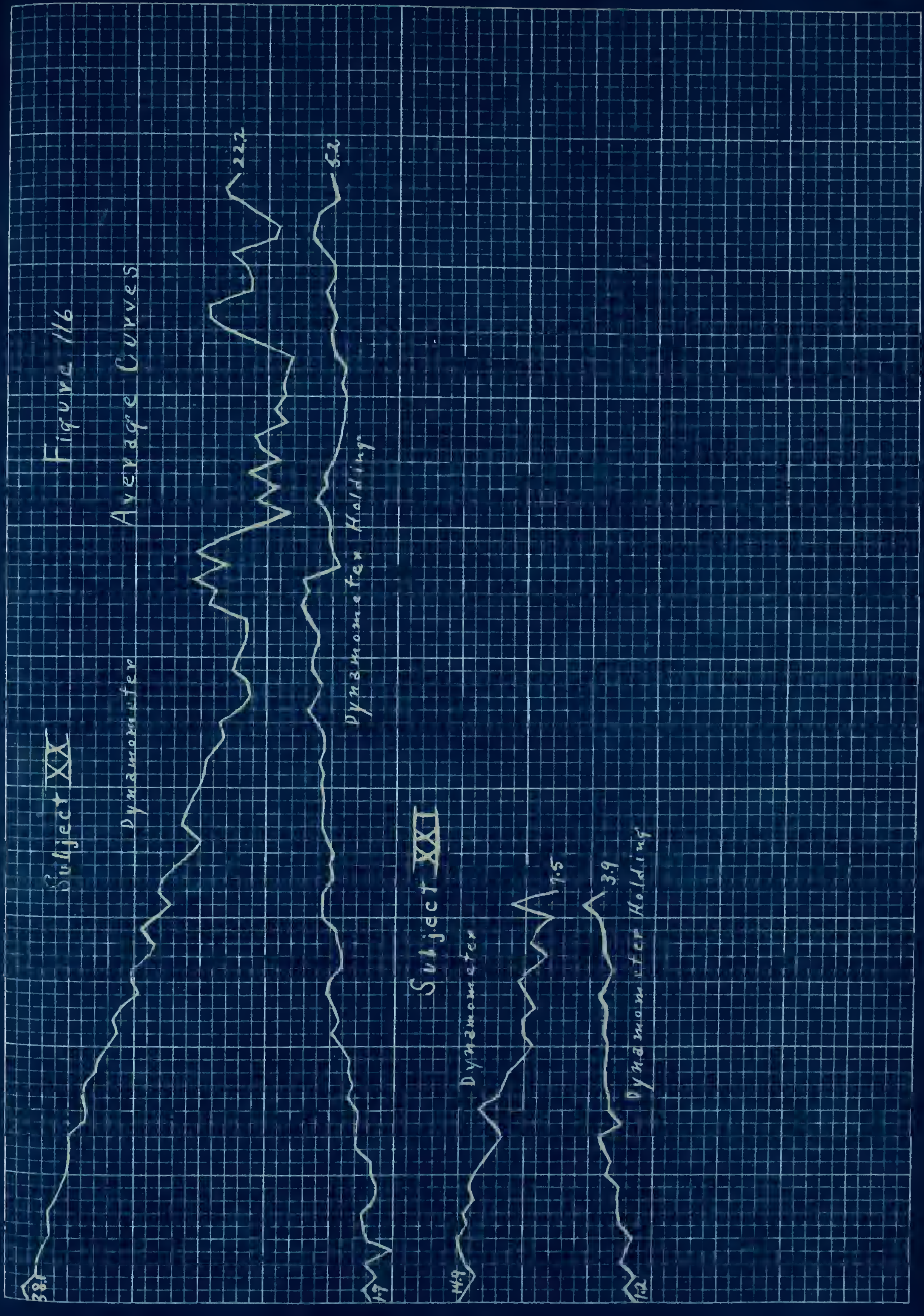
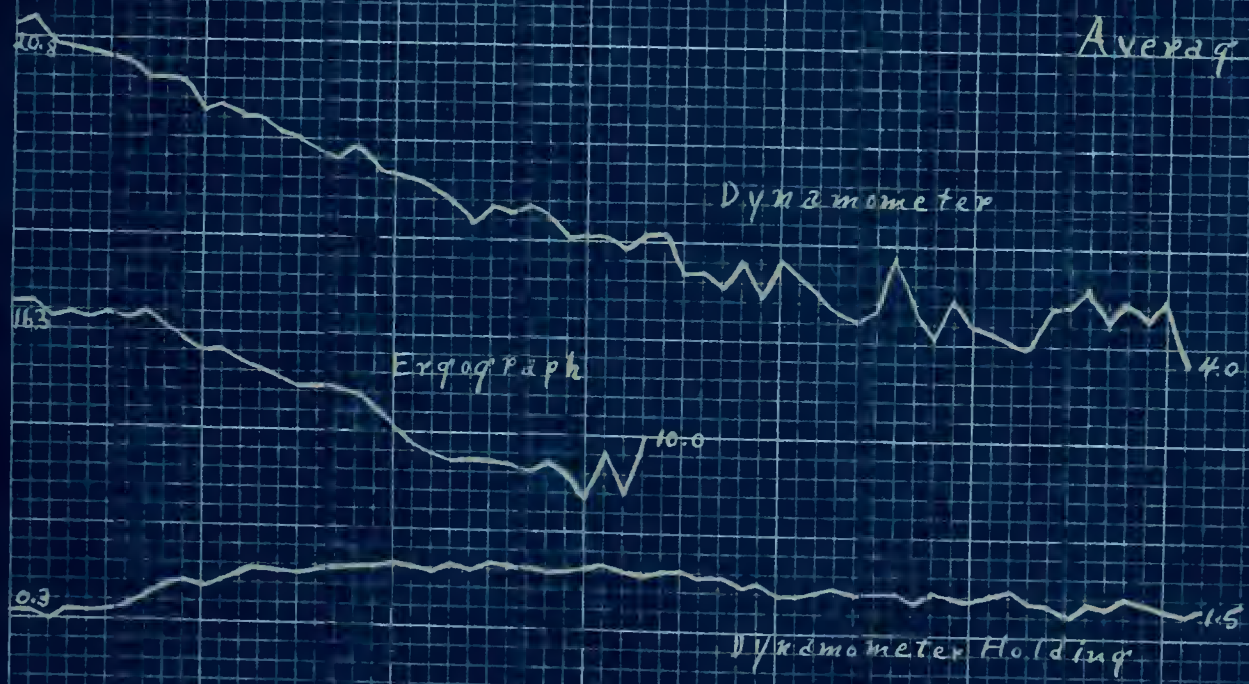



Figure 116
Average Curves

Figure 117

Average Curves of Subject XXII



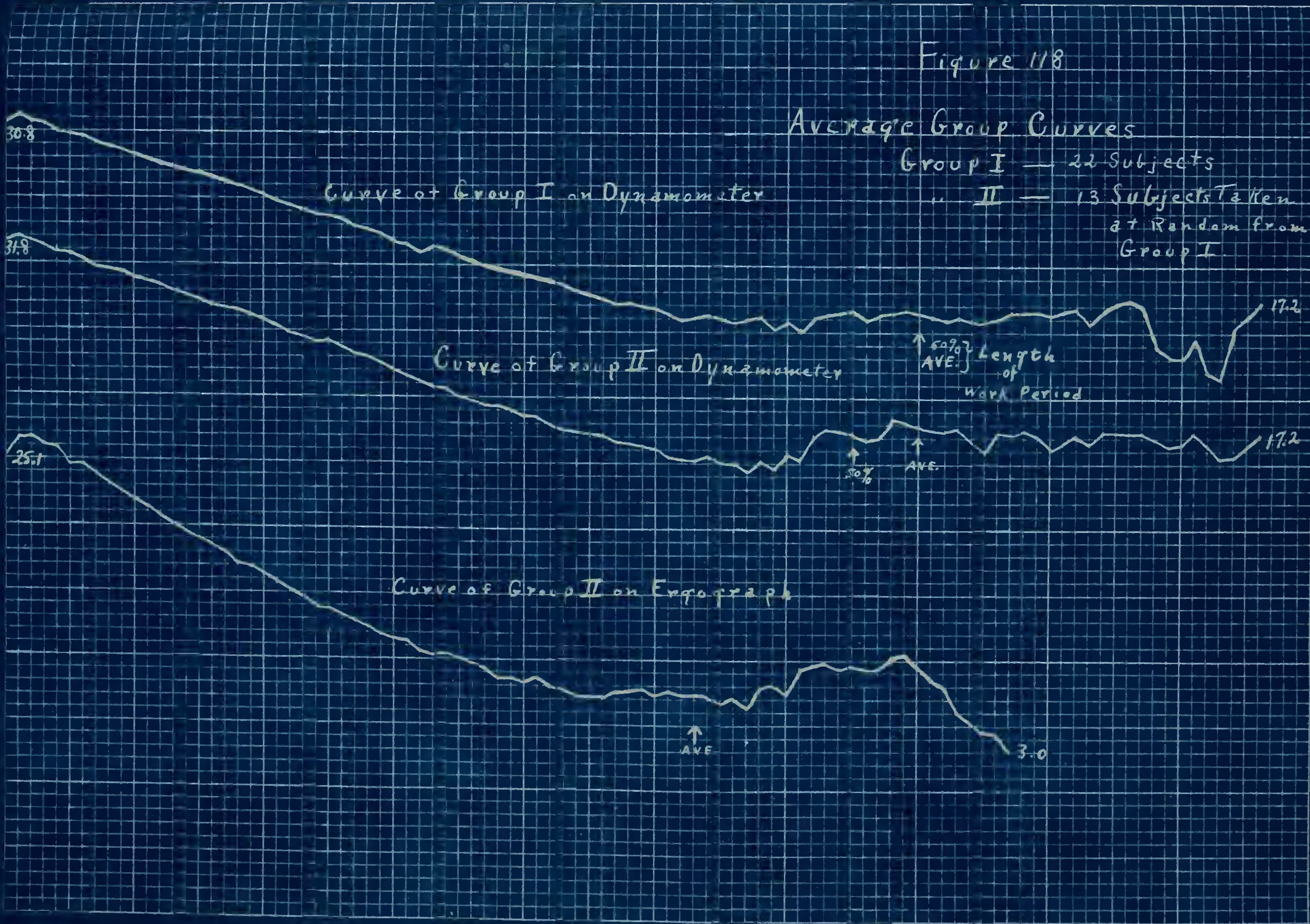


Figure 118
Average Group Curves
Group I — 22 Subjects
" II — 13 Subjects Taken at Random from Group I
Curve of Group I on Dynamometer
Curve of Group II on Dynamometer
Curve of Group II on Ergograph
30.8
31.8
25.1
17.2
17.2
3.0
50% AVE. } Length of Work Period
50%
AVE.
AVE

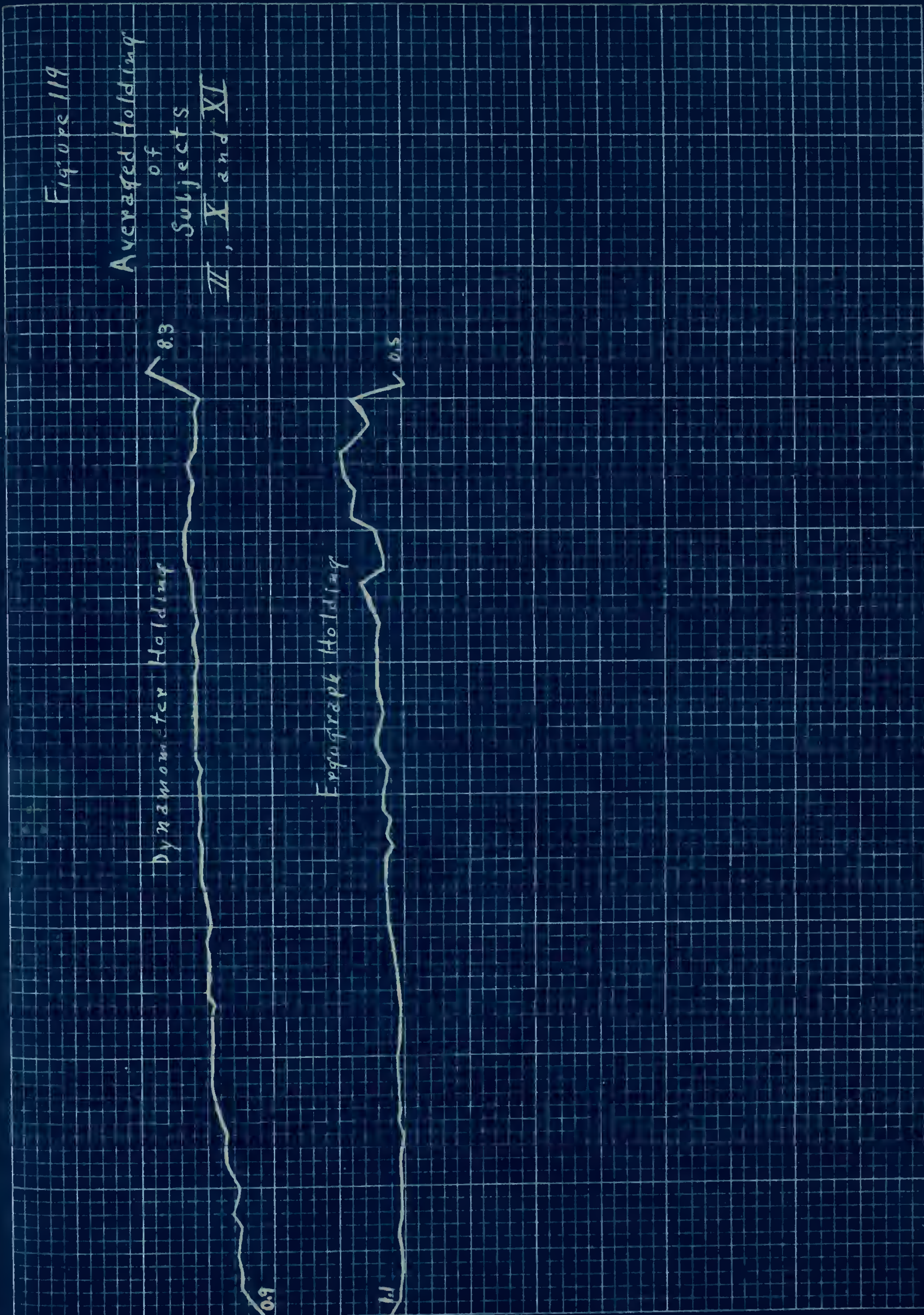


Figure 119
Averaged Holding of Subjects II, X and XI
0.3
0.5
Dynamometer Holding
Ergograph Holding
0.9
1.1

C. DISCUSSION OF THE AVERAGE FATIGUE CURVES TAKEN ON THE ERGOGRAPH AND DYNAMOMETER.

In treating the individual average fatigue curves, and the average curves for the group in both studies as they appear in Figures 99 to 119, their limitations must be realized. The individual average curves are considered first. These average curves, especially in the case of those on the dynamometer, again illustrate decidedly the principle of individual differences. Variation from individual to individual is not so marked in the case of the ergograph curves, however. It will be noticed that in each instance the dynamometer curve is drawn first, then, in the case of the thirteen subjects of study II, the ergograph curve is placed below it. Average holding curves appear at the bottom of each sheet. In the majority of cases, these average curves can be considered indicative of an individual's performance. Of course, averaging smooths out daily irregularities. Likewise it introduces some artifices which must be considered in interpretations. The majority of individuals in their average curves of both studies show a decided end spurt. Now it will be recalled that this phenomenon was rare among the individuals in both studies. Why should the majority of individuals now show end spurts? The explanation is simple when one recalls that these averages are taken from curves of different lengths. Naturally the end points of the longer curves will, in averaging, influence the group tendency and distort the true picture. In most cases then any end spurt that appears is due to the influence of one or two longer curves. It is hard to tell what effect averaging has upon the initial contraction of those individuals who do not exhibit consistent daily beginnings. Certainly in the case of those who start nearly the same each day, the picture presented for the initial contractions in the average curve is a fair one.

In regard to the question of whether or not relatively related muscle groups give the same type of a fatigue picture when doing relatively similar work, one must seek a partial answer in the analysis of the average curves of those individuals participating in both studies. Certain considerations must be kept in mind, however, before drawing any conclusions. While the muscles involved in the finger-pulling of ergography constitute a small part of the larger group involved in gripping, one can but conjecture as to whether or not the two functions are closely related. It is quite evident that the two instruments and the conditions under which the subject is required to do work are not the same. Likewise one method is based upon an isometric measurement and the other upon an isotonic measurement. The limitations of each method have already been emphasized. Yet emperically, at least, one can make the assumption that the two tasks are relatively similar. If the fatigue curves for these two tasks should happen to be similar, while it would not be conclusive evidence that the two functions are similar, it would go a long way in substantiating an ordinary guess. It would indicate at least that the dynamometer is as good a method for measuring fatigue of the larger muscle groups as the ergograph is for the smaller muscle groups. One realizes of course that in the present state of ergography, this statement may not be saying much in behalf of the dynamometer as an instrument for measuring fatigue--but it would be saying more in its favor than has been said for some time.

However, the facts must speak for themselves. An analysis of the individual average curves on the ergograph was made in order to compare these curves with those on the dynamometer. Table XI, page 240, presents a comparison of these curves with respect to certain salient features such as strength as determined by the kilogram ratio between the two tasks, length, incline or drop, beginning, ending, and general contour. A cross under the letters M, L, or E, indicates whether the ergogram is more, less, or equal to the dynamometer recording with respect to strength, length, or incline. A cross under the letters S or D indicates whether the ergogram is similar or different from the dynamometer recording with respect to beginning, ending, or general contour. The kilogram ratio indicates the degree of difference between the strength or height of contractions in the two recordings. The height of contraction, of course, is always greatest on the dynamometer.

On the average, the dynamometer contractions are about thirteen times as great as those registered on the ergograph. In one case they were as much as twenty times as great. Because of the way in which the curves are plotted on the cross-section paper, a ratio of 1-10 would indicate that, relatively, the curves were of equal strength. The initial and final contractions listed on the graphs for the ergograms can be stated in terms of kilograms by referring to Table I, and translating accordingly. If the ratio falls anywhere from 1-9 to 1-11,

TABLE XI. A Comparison of Individual Average Curves Upon the Ergograph with Individual Average Curves Upon the Dynamometer.

| Subject | Strength M | Strength L | Strength E | Length M | Length L | Length E | Incline M | Incline L | Incline E | Beginning S | Beginning D | End S | End D | Kilogram Ratio | General Contour Similar | General Contour Different |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| I. | | X | | | X | | X | | | X | | X | | 1-12 | X | |
| II. | | | X | | X | | X | | | | X | X | | 1-11 | | X |
| VI. | | | X | | X | | X | | | X | | | X | 1-10 | X | |
| VII. | | X | | | X | | | | X | X | | | X | 1-14 | X | |
| X. | | | X | | | X | | | X | X | | X | | 1-11 | X | |
| XI. | | X | | | X | | X | | | X | | | X | 1-12 | X | |
| XII. | | X | | | X | | | X | | X | | | X | 1-20 | X | |
| XIV. | | X | | | X | | X | | | X | | | X | 1-12 | | X |
| XV. | | | X | | X | | X | | | | X | X | | 1-10 | | X |
| XVI. | | X | | | | X | | | X | X | | | X | 1-15 | X | |
| XVII. | | X | | | | X | | | X | | X | X | | 1-17 | X | |
| XVIII. | | X | | | X | | X | | | | X | | X | 1-15 | | X |
| XXII. | | X | | | X | | | | X | | X | | X | 1-14 | | X |
| | | 9 | 4 | | 10 | 3 | 7 | 1 | 5 | 8 | 5 | 5 | 8 | 1-13 | 8 | 5 |

the two curves are considered of equal strength. Anything over 1-11 indicates that the ergogram is weaker in relation to the dynamometer recording, and is indicated accordingly by a cross under L. The length of the curves can be seen by inspection. Any pair of curves within five seconds of each other are considered equal. Incline can be determined readily by measuring the distance between the two curves at various points along the ordinates. If the distance remains relatively constant, the incline is considered equal. If the distance increases noticeably, the incline of the ergogram is greater and is checked under M. If the distance decreases, as it does in the case of Subject XII (Figure 108) the incline of the ergogram is less and is checked under L. The beginning, ending, and general contour can be determined readily by inspection and comparison of point for point contractions.

In all but four cases the ergograms are weaker than the fatigue curves of the dynamometer. They are equal in strength in the four cases (Subjects II, VI, X, and XV). Ten of the thirteen ergograms, or 77%, indicated that the same subjects worked for a shorter time than they did on the dynamometer. The incline in general tends to be steeper for the ergograph fatigue curve than for that of the dynamometer. Five subjects however show fairly equal inclines and in only one case was the drop greater on the dynamometer recording. The two curves are more often apt to begin similarly than not. Nothing much can be said in regard to endings. Table XI would indicate that the endings of the two curves tend to be unlike, but with the abnormal influence of a few individual curves determining the ending of these average curves little can be said. Like the beginnings of the two curves the general contour tends to be similar in 61% of the cases.

This analysis seems to indicate that in general the two fatigue curves resulting from work upon the dynamometer and the ergograph respectively, are very much alike in contour, but the ergogram is usually weaker, shorter, and steeper. In one case only, subject X, were the two curves practically identical in strength, length, drop, and contour. An examination of the group curves is necessary before general conclusions relative to fatigue in the two muscle groups can be made.

Figure 118 presents the fatigue curves for the group in both studies. The first curve is the general curve for the twenty-two subjects who worked on the dynamometer alone. The second curve is the general curve for fatigue on the dynamometer of those thirteen subjects who participated in both studies. The third curve is the general curve for fatigue on the ergograph for these same thirteen subjects.

The dynamometer curves for the entire twenty-two and the special thirteen can be said to be very much alike. There is a slight bit of initial warming-up, a long gradual decline, a general leveling off, a gradual rise toward the end, a final dip followed by what appears to be an end spurt. As was the case with the individual average curves, the true endings of these general group curves are masked because of the influence of a few subjects who produce long strong curves. As the arrow indicates, in the general group curve for the twenty-two subjects, the average length of work period was 69 seconds. In this study, 69 seconds also represents the work period for 50% of the subjects. After the 69th second, the curve begins its gradual end rise. This end rise is brought about chiefly through the influence of five subjects, namely, Subject IV, V, VI, XVIII, and XX. All of these have unusually long curves, and with the exception of Subject V, the end points of these curves are high. Of the eleven subjects who do work after the 69th second, all finish before the 75th second except for the five people already mentioned. Of these, Subject IV ends at the 80th second and the end spurt from here to the 87th second is largely the work of Subjects VI, XVIII, and XX. The end spurt would be much higher if it were not for the low level of work carried on by Subject V at the same time. The influence of Subject V can be seen after the 87th second when VI and XX drop out of the picture. The curve continues to drop until Subject V finishes. The sudden rise in the last three seconds constitutes the work of Subject XVIII alone.

A similar influence is exerted by a few to determine the ending in the second curve which represents the work of only the special thirteen subjects on the dynamometer. In this curve, the 69th second again represents the length of the average work period. Fifty per cent of the subjects finish before the 54th second, however. Subject V was not a member of this group, and her low curves do not hold down the higher and longer ones of Subjects VI and XVIII. Subjects IV and XX do not appear in this second group. Hence, the curve rises more abruptly to the 77th second than did the first group curve. After the 77th second, the level stretch is the work of Subjects VI and XVIII, and when Subject VI finishes at the 89th second, the ending of the curve is the work of Subject XVIII only. In general, the two curves for the two groups upon the dynamometer are quite similar. The nine subjects who failed to participate in the second study do not influence the group picture upon the dynamometer to any great extent.

The general curve for work upon the ergograph is the third curve in Figure 118. On the whole it is very similar to the work done by the same thirteen subjects on the dynamometer except for the ending--which again is due to the work of a few (four) individuals. The general fatigue curve for the group for work done upon the ergograph shows a more decided warming-up period than was true in the case of dynamometer study. Likewise the ergograph curve is shorter and shows a more rapid drop especially in the early part of the curve. The gradual leveling off, and the sudden end rise beginning about the 57th second is the same as in the dynamometer study. The final drop, however, is not characteristic of both studies. The average length of the work period upon the ergograph is about 52 seconds. The rise after the 57th second is due to the work of Subjects X, XI, XIV, and XVIII. In this study the end points for Subject XVIII are the lowest of this final group. It will be recalled that his endings were the highest of the group in the dynamometer study. Subject 14 drops out in the early part of the rise leaving Subjects X and XI primarily responsible for the increasing height. After about the 52nd second the rise can be attributed to Subject X alone. It would be higher still if Subject XVIII did not hold it down. When Subject X finishes at the 73rd second, the final sudden drop represents the work of Subject XVIII alone.

On the whole, the group curves on the ergograph and the dynamometer are quite similar. One would expect the fatigue curve on the ergograph to be shorter, weaker, and more rapid than that upon the dynamometer. Such is the case as both the individual and group averages show. The dropping-off is not as pronounced in the group curve upon the ergograph as it is in some of the individual averages, but the rate of decline is slightly greater than what appears in the group curve on the dynamometer. The fact that the muscles involved in the finger pulling of ergography is not as well developed as those for gripping alone would lead one to expect these results. Since the degree of similarity in the two fatigue curves is so close, one may well postulate that related muscle groups doing relatively the same type of physical work show corresponding fatigue characteristics. Whether this generalization can be extended to all muscle groups doing similar work--as in arm ergography, leg ergography, etc.--can not be determined by reference to the present study. It would seem reasonable, however, to expect that similar conditions would hold in these instances. It was hoped that the study could be extended into other muscles groups, but time did not permit. It would seem from this study that the dynamometer is as good an instrument for measuring muscular fatigue of the larger muscle groups as the ergograph is for the smaller muscle groups. In fact, as far as keeping conditions constant is concerned, the isometric technique employed is to be preferred. The biggest difficulty with both instruments at the present time is the problem of keeping one group of muscles relatively isolated and as free from the influence of other muscles as possible. Both instruments are found lacking in this respect.

## D. GENERAL SUMMARY

I. <u>Problem</u>

A. The present study is an attempt to find an answer to the following questions:

1. What is the nature of fatigue curves in the integrated organism as a result of muscular work done under experimental conditions?
2. How do fatigue curves of a given individual compare with reference to different muscle groups doing relatively similar work?
3. What are the possible reasons for individual variations?
4. Are these curves similar under similar conditions for all people or do differences between individuals exist?
5. What are the implications of such a study?

II. <u>Method of Investigation</u>

A. Study divided into two parts:

1. A study of the fatigue curves for the muscle group involved in gripping a revised hand dynamometer.
    a. Working conditions held as constant as possible.
    b. Practiced group of twenty-two subjects, largely college students. (eight women, thirteen men, and one boy)
    c. Daily report of each subject in order to check on such factors as previous activity, food intake, sleep, physical condition, etc., which may influence the curves.

d. Graphic analysis of data collected.

2. A study of the fatigue curves for the muscle group involved in pulling on a spring ergograph.

a. Conditions same as in study #1 except for type of appartus used.

b. Thirteen of the same subjects taking part in study #1 (six women, seven men).

(1) Practice period on new apparatus before collection of data.

c. Same daily reports as in study #1.

d. Graphic analysis of data collected.

B. Comparison of the fatigue curves of both studies.

III. <u>Conclusions:</u>

A. Study #1.

1. While the daily fatigue curve resulting from work upon the dynamometer is much the same for a given individual, marked differences are evident between individuals.

a. The cause for differences between individuals seems to be a matter of personal muscular functioning, and is not due to anything especially inherent in the experimental set-up.

b. Whether individual differences in muscular fatigue can be associated with any general personality differences is merely a matter of conjecture as far as this study goes. On the surface, it seems that certain steady personality types produce more consistent curves than unreliable personality types.

2. The type of activity prior to the work period upon the dynamometer is the greatest single factor in causing daily variation in any single individual.
   a. Eating just prior to the work period has the effect of shortening the curve considerably. Usually curves taken under this condition are weaker and drop off more rapidly.
3. Time of day seems to have some effect upon changing the fatigue curve, in that the curves of a certain few subjects group definitely into morning, noon, and afternoon divisions. The morning curves are similar to each other but different from the afternoon curves and vice versa.
   a. Morning curves are more apt to be similar than are afternoon curves.
4. The effect of lack of sleep and late parties upon the fatigue curve in so far as it can be traced varies from individual to individual.
5. A subjective estimate, or mental set of weakness or strength influences the curve in some cases. Estimates often uncertain, but in this study they correspond more often than not.
6. Emotional tension and general excitement usually affect the curve in the following manner:
   a. Initial high level of work
   b. Rapid irregular decline
   c. Curve longer than usual

7. Effect of hard physical work prior to recording has similar effect as emotional tension, except curves are shorter than usual.

8. In the single instance available for study, a period of twenty-three years between subsequent recordings made no appreciable difference in the nature of the fatigue curve produced by this subject on the dynamometer.

9. Some curves show the special phenomena of practice effects, warming-up, initial spurt, and end spurt.

   a. Warming-up more common

   b. Initial spurt rare

10. Holding effect always present and usually of three types:

    a. Type I--Little or no holding to begin with but more and more as fatigue sets in.

    b. Type II--Early high holding, relaxation, and finally a final rise as fatigue sets in.

    c. Type III--Irregular and usually less toward the end.

11. Amount of holding can be decreased with conscious effort.

12. If daily holding is consistent, daily fatigue curves are quite apt to be consistent and vice versa.

B. Study #2.

   1. Individual differences not so marked for fatigue curves resulting from work on the ergograph.

2. Time of day has little effect upon shape of curves. Curves more often similar regardless of time of recording.

3. Type of work prior to recording is again the greatest single variable affecting the nature of the curve.

4. Eating prior to recording seems to have similar effect as in Study #1.

5. Subjective estimates of strength tally less with production than in Study #1.

6. Influence of lack of sleep again dependent upon individual.

7. Poor physical condition causes weak irregular production.

8. Emotional tension has similar effect upon fatigue curve as in Study #1.

9. Warming-up decidedly more common for work upon the ergograph than upon the dynamometer. End spurt and initial spurt less common upon the ergograph.

10. The presence of an audience greatly influences the fatigue curve. Higher production but a more rapid dropping off.

11. Holding rare and when present seems to be an individual characteristic.

    a. If holding, when present, is consistent, fatigue curves more apt to be consistent; holding irregular, fatigue curves usually irregular.

b. Can be completely eliminated by practice.

C. Comparison of the two studies:

1. Individual average fatigue curves from work upon the dynamometer and the ergograph are often very similar in general contour, but the ergogram is usually weaker, shorter, and steeper.

   a. This may be because a smaller and less developed set of muscles are functioning.

2. The group curve of fatigue from work upon the dynamometer is quite constant, both for the large group of twenty-two subjects and for the smaller group of thirteen subjects.

   a. Slight initial warming-up

   b. Long gradual decline

   c. Leveling off

   d. Exhibits end rise, but true end masked by influence of a few abnormally long curves.

3. Group curve of fatigue upon the ergograph is very similar to the group curve for the dynamometer.

   a. Warming-up period more definite

   b. Decline slightly steeper

   c. Leveling off like group curve of Study #1

   d. Has similar end rise as group curve of Study #1. True end again masked.

4. In general then the fatigue curves of related muscle groups doing relatively the same type of work exhibit similar characteristics.

5. The dynamometer as constructed is as good (if

not better) an instrument for the measurement of fatigue in the larger muscle groups than is the spring ergograph for the smaller muscle groups.

a. The isometric measurement of the dynamometer is to be preferred to the isotomic measurements of either the spring or weight ergographs.

IV. <u>Suggestions for further study:</u>

A. Since this investigation in itself is far too general an undertaking, special parts of it need further special emphasis.

1. The construction of a finger, arm, and leg ergograph utilizing an isometric spring so that better comparisons may be made of the fatigue curves of other related muscle groups.
2. A study of the effect of eating alone upon the fatigue curve of these muscle groups.
3. A study of the effect of <u>specific</u> tasks prior to recording upon the fatigue of these muscle groups.
4. The relation of certain personality traits to the nature of the fatigue curve.
5. Pen and ink recording upon cross section kymograph paper would save much time and labor.
6. Some method must be found to determine the actual amount of <u>work</u> done on dynamometer and the isometric spring ergograph in order for better statistical interpretations to be rendered.

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# A P P E N D I X

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KEYS TO INDIVIDUAL CURVES

IN

DYNAMOMETER STUDY

Subject I. Work Curves on Dynamometer.

A. Morning curves--12 noon

I. Mental Work previous (curves 3, 4, and 5.)

a. 3 and 4 similar. Activity, writing. Other conditions constant.

b. 5 irregular. Activity, photography. Other conditions constant except high strength estimate.

II. Physical work previous (curves 1, 2, and 6.)

a. 1 and 2 similar. Activity, bicycling. Other conditions constant.

b. 6 irregular. Activity, bicycling. Other conditions constant except emotionally upset; frightened by dog and fell from bicycle.

B. Curves after eating--12:30 p.m.

I. Curves 7 and 8 dissimilar and unlike morning curves as well.

a. 7, same conditions as 1 and 2, except lunch previous to taking record.

b. 8, same as 7, except less sleep and late party the night before.

C. Afternoon curves--2:30 p.m.

I. Mental work previous--writing.

a. Curves 9 and 10 similar but unlike curves in morning and after eating. Other conditions like 3 and 4.

D. Summary:

I. All morning curves generally similar. Slight variations probably effected by such changes in conditions

Subject I, continued.

as type of work previous to recording, emotional upset, and high estimate of strength.

II. Afternoon curves similar to each other but unlike morning curves. Only apparent variable is time of day.

III. After dinner curves unlike morning or afternoon group. Only apparent reason they differ from each other is because of sleep variable. Shorter and irregular.

IV. Change in time of day seems to be important factor in shaping curves.

Subject II. Work Curves on Dynamometer.

A. Morning curves--10 to 12 a.m.

I. Mixed work--laboratory routine previous.

a. Curves 1, 2, 3, and 6 similar, conditions constant with exception of curve 2 which shows no apparent effect because of sick stomach and low estimate of strength that day.

II. Mental work previous (curves 4 and 5 similar)

a. 4, activity lecturing and smoking.

b. 5, activity photography. High strength estimate may account for variation.

B. Curves after eating--12:30 p.m.

I. Curves 7 and 8 similar but unlike morning group. Conditions similar to morning group.

a. Curve 8, conditions same as 7 except less sleep and late party.

C. Afternoon curves--4 p.m.

I. Mixed work, laboratory routine (curves 9 and 10). Curves dissimilar.

a. 9 resembles morning curves. Conditions same except for time of day.

b. 10 slightly resembles after dinner curves. Conditions like 9 but less sleep.

D. Summary:

I. All morning curves generally similar. Slight variations due to type of work previous to recording, and to high estimate of strength.

II. Afternoon curves dissimilar and form no clear-cut group.

Subject III. Work Curves on Dynamometer.

A. Morning curves--12 noon.

I. Mental work previous (curves 1 - 4)

a. 1, 2, and 4 similar. Activity, attended class. Conditions constant.

b. 3 different. Conditions same as above except for taking hour examination.

B. Curves after eating--1:00 p.m.

Curves 5 and 6 similar and slightly different from morning curves. Conditions same as morning except for lunch previously and low estimate of strength.

C. Summary:

I. Important variables are time of day, emotional strain from examination, and low estimate of strength.

Subject IV. Work Curves on Dynamometer.

A. Morning curves--11:00 a.m.

I. Mental work, attending class. (curves 1 - 3)

a. Curves 2 and 3 similar, but conditions quite different.

b. Curve 1 irregular, but conditions same as 2.

B. Afternoon curves.

I. Early afternoon, 2 p.m.

Curves 4 and 5, dissimilar. Both short.

a. 4--previous activity, resting.

b. 5, conditions same as 4 except attended class previously. Shape similar to morning curves.

II. Late afternoon, 3:45 p.m.

Curves 6 and 7, similar. Attended class previously. Conditions similar to 5. Shape similar to morning curves.

C. Summary:

I. Time of day seems to have little effect on shape of curve except curves at 2:00 p.m. nearest dinner hour are shorter.

II. No apparent reason for curve 1 to differ so distinctly from curve 2 when conditions were constant. Every reason to expect curve 3 to differ from curve 2 because of lack of sleep, late party, low estimate of strength.

III. Resting before recording seems to smooth out curves.

Subject V. Work Curve on Dynamometer.

A. Morning curves--9:45 a.m.

Mental work previous.

Curves 1 - 6 very similar. Activity, map-making and tabulating. Conditions constant. (curve 6 shorter than usual)

B. Afternoon curves--2:00 p.m.

I. Mental work previous

Curves 7 and 8, generally similar but unlike morning curves.

7, high points due to presence of spectator who encouraged subject verbally. Otherwise conditions similar to 8.

C. Summary:

I. Morning curves alike but differ from afternoon curves in length and contour.

II. Spectator influence great.

Subject VI. Work Curves on Dynamometer.

A. Morning curves--10:00 a.m.

I. Mental work previous. Curves 1, 3, 4, and 5. Activity, attending class.

a. 1 and 3 similar. Conditions same.

B. 4 and 5 similar. Conditions same, but differ from 1 and 3 in having more sleep, quieter evenings, and no food for 15 hours previously.

II. Physical work previous. Curve 2. Activity, carpentry. Other conditions same as 4 and 5, but curve similar to 1 and 3.

B. After dinner curve.--1:30 p.m. Curve 6. Shortest curve but similar to morning curves in shape. Conditions unlike morning curves--rest and lunch previously, and much less sleep.

C. Afternoon curves--3:00 p.m.

I. Physical work previous. Curves 7 and 8, dissimilar.

a. 7, sawing wood previously. Conditions similar to 2 but resembles after dinner curve.

b. 8, went to fire just previous. Curve like 1 and 3 but very irregular--excited, not much sleep.

D. Summary:

I. All curves relatively similar.

II. Variations caused chiefly by type of work previous to record; lack of sleep; general excitement.

Subject VII. Work Curve on Dynamometer.

A. Morning curves--9:30 a.m.

I. Mental work previous. Curves 1 and 6, dissimilar. Conditions similar except for activity.

a. 1, laboratory work previous.

b. 6, tabulating charts.

II. Physical activity, walking. Curves 2, 3, 4, and 5. Curves similar. Sleep only variable.

B. Afternoon curves.--3:00 p.m.

I. Mental work--study. Curves 7 and 8, dissimilar. Conditions for curve 8 same as for 7 except for late party night before, and low estimate of strength. (Same amount of sleep, though.)

C. Summary:

I. Not much difference between morning and afternoon curves except curve 8.

II. Chief variable seems to be amount of sleep. Subjective feeling of weakness also affects curve.

Subject VIII. Work Curves on Dynamometer.

A. Morning curves--9:45 a.m.

I. Mental work, tabulating and copying records. Curves 1 -- 4, similar. Conditions constant.

a. Curve 1, slight variable--estimate of strength higher than usual and curve also slightly longer and higher than rest.

B. Afternoon curves-- 2:00 p.m.

I. Restful work. Curves 7 and 8, similar. Conditions constant except for activity.

a. Sorting cards previous

b. Rest previous and rode to laboratory.

C. Estimates strength much lower than usual, curves short, but not affected much by subjective feeling of weakness.

C. Summary:

I. Morning curves similar to afternoon curves, except for length.

II. Conditions relatively constant other than time of day.

III. Subject does not always estimate strength in accordance with production.

Subject IX. Work Curves on Dynamometer.

A. Morning curves--10:30 a.m.

   I. Mental work, study. Curves 1 -- 3, similar. Conditions constant.

      a. Curve 2 has odd ending for no apparent reason.

B. Afternoon curves--3:00 p.m.

   I. Mental work. Activity, attending class. Curves 4, 5, and 6. Dissimilar and unlike morning curves. Conditions constant except for estimates of strength which correlate negatively with levels of performance.

C. Summary:

   I. Afternoon curves unlike morning curves and unlike each other.

   II. Estimates of strength do not correspond with performance.

<u>Subject X</u>. Work Curves on Dynamometer.

A. Morning curves.

  I. Mental work, teaching. Curves 1 - 6, similar. Conditions quite constant.

    a. Curves 1, 2, and 3 more similar to each other than others. Estimate of strength low for these curves, but much lower in curve 1 than performance warrants.

    b. Curves 4, 5, and 6 more alike. Estimates of strength high, as is level of performance.

B. Afternoon curves--3:00 p.m.

  I. Mental work, office and conference. Curves 7 and 8, similar to each other and similar to morning curves.

    a. conditions for 8 same as for 7, but a little less sleep.

C. Summary:

  I. Fairly constant level of performance under similar conditions.

Subject XI. Work Curves on Dynamometer.

A. Morning curves.

I. Physical work, walking. Curves 1 and 2, dissimilar.

a. Curve 1, 8:45 a.m., fails to catch rhythm.

b. Curve 2, 10:45 a.m., probably typical.

B. Curves after eating.

Curves 3 and 4, very similar. Conditions constant. Shorter than morning or afternoon.

C. Afternoon curves--2:00 p.m.

I. Physical work, dish washing. Curve 5, shorter but not too dissimilar from rest of afternoon curves.

II. Mental work, correcting examinations. Other conditions came as curve 5. Curves 6 - 10, all very much alike.

D. Summary:

I. Afternoon curves similar, conditions constant except in curve 5.

II. After dinner curves similar, but shorter and unlike afternoon curves.

III. Nothing definite about morning curves. Subject unable to make morning appointments in order to get more records.

<u>Subject XII</u>. Work Curves on Dynamometer.

A. Morning curves--10:00 a.m.

I. Mental work, attending class. Curves 1 and 2, fairly similar. Conditions constant.

B. After dinner curves--1:00 p.m. Curves 3 and 4 similar and quite like morning curves. Conditions constant.

C. Afternoon curves--3:00 p.m.

I. Mental work. Curves 5 and 6, not too much alike yet follow general trend of morning curves. Conditions fairly constant.

a. Curve 5, making charts just previous.

b. Curve 6, adding machine calculations just previous. All other conditions same as 5.

D. Summary:

I. Tends to produce same general type of curve regardless of time of day, except for slight irregularity in last two curves.

Subject XIII. Work Curves on Dynamometer.

A. Morning Curves--9:00 a.m.

   I. Mental work class and study. Curves 1 - 6. In general, similar, except curves 4 and 5 do not exhibit initial warming-up. Conditions constant.

B. After dinner curves--1:00 p.m. Curve 7 only. Conditions the same as for morning curves except for dinner. Curve is like morning curves.

C. Afternoon curves--2:00 p.m.

   I. Mental work, class. Curves 8 and 9, dissimilar, also differ somewhat from morning curves.

      a. 8, conditions same as above except time of day. Sharp final drop.

      b. 9, approaches morning trend but is extremely short and steep. Subject estimates strength as three--heretofore has estimated seven. All other conditions same as 8.

D. Summary:

   I. Curves tend to follow same trend throughout day as conditions remain constant except for time of day.

   II. Subjective estimate of strength seems to correspond with performance.

Subject XIV. Work Curves on Dynamometer.

A. Morning Curves--10:00 a.m.

I. Mental work. Curves 1 and 2, somewhat similar. conditions constant except for type of activity previous to record taking.

a. 1, attending class.

b. 2, taking examination. Other conditions same as curve 1. End of curve more erratic, however.

B. After eating curves--1:00 p.m.

I. Curve 3, similar to morning but shorter.

II. Curve 4, not much different from 3, but lacks initial warming-up. Other conditions constant.

C. Afternoon curves--3:00 p.m.

I. Mental work, making charts. Curve 5, unlike morning curves. Subject feels ill, but performs more work than at any other time.

II. Physical work, swimming previous. Curve 6, unlike curve 5 or morning curves. Other conditions same as curve 5--still feels ill--head cold.

D. Summary:

I. First four curves similar, except those after dinner are much shorter.

II. Conclusions can not be drawn from afternoon curves, except that physical condition influences curve.

III. Type of work previous to recording definitely affects curve.

Subject XV. Work Curves on Dynamometer.

A. Morning curves--12 noon.

  I. Mental work, attends class (except curve 1).

  Curves 1 - 5, similar, except curve 1.

    a. Curve 1 shorter and steeper. Conditions same as other morning curves, excppt attends assembly instead of class. Also attends lecture night before instead of usual study.

B. Afternoon curves, 2:45 p.m.

  I. Mental work, class previous. Curves 6 and 7, similar. Not much different from morning curves except shorter.

    a. Curve 7, conditions same as 6 except more sleep. Subject seems to get along on very little sleep at all times.

C. Summary:

  I. Curves on whole are similar, no clear cut reasons for variation.

  II. End spurts common.

Subject XVI. Work Curves on Dynamometer.

A. Morning curves--9:00 a.m.

I. Mental work, class attendance. Curves 1 - 4. Curves not too similar except 1 and 2. Conditions constant, except subject varies in estimates of strength. Strength estimate does not coincide with performance, however.

B. After eating curves--1:15 p.m. Curves 5 and 6, very similar but unlike morning. Much shorter than morning curves. Estimates of strength vary widely, but do not accord with performance in either case.

C. Afternoon curves--3:00 and 4:00 p.m.

I. Mental work, correcting papers previously. Curves 7 and 8, similar. Unlike morning and after dinner curves. Conditions constant. Estimate of strength in each case higher than level of performance.

D. Summary:

I. Time divides curves into three categories, with curves in each category more or less similar.

II. Curves after eating shorter and steeper.

III. Estimates of strength do not coincide with performance in any respect.

Subject XVII. Work Curves on Dynamometer.

A. Morning curves--9:40 a.m.

I. Mental work, routine office work.

Curves 1 - 5, similar. Conditions constant.

B. After eating curves--1:30 p.m.

Curve 6, unlike morning. Very short and abrupt--very busy lunch hour--quite excited.

C. Afternoon curves--2:45 p.m.

I. Mental work, typing previous.

Curve 7, similar to morning curves except for end spurt. Conditions same as curves 1 - 5 except for time of day.

D. Summary:

I. Curves in general are alike, except after eating.

II. Extreme excitement may be cause for extreme variation in after dinner curve.

Subject XVIII. Work Curves on Dynamometer.

A. Morning curves--11:00 a.m.

I. Mental work, lecturing just previous. Curves 1 - 4. Curves somewhat alike. Conditions constant except introspective reports in 3 and 4.

a. Curve 3, subject estimates strength as very weak. Curve is shorter but level of work is much greater than estimate.

b. Curve 4, subject estimates strength as maximum. Record went to limit of instrument, and subject could still have continued work. Only instance where instrument was found too short to take care of any record.

B. Afternoon curves--3:30 p.m.

I. Mental work, conference and study. Curves 5 and 6, similar. About same as morning curves except more initial warming-up. Conditions constant.

C. Summary:

I. Curves very similar with conditions quite constant.

II. Strongest subject in study as far as endurance and high level of performance go.

III. Estimate of strength not always in accord with performance.

Subject XIX. Work Curves on Dynamometer.

A. Morning Curves--10:00 a.m.

I. Mental work, study previously.

Curves 1 - 4, similar, Conditions constant except for strength estimates, which correlate negatively with performance.

B. Afternoon curves--3:00 p.m.

I. Mental work, class attendance.

Curves 5 and 6, dissimilar. Both shorter and steeper than morning curves, however. Conditions constant, except estimates of strength which again vary inversely with performance.

C. Summary:

I. Morning and afternoon curves form two distinct groups.

II. Afternoon curves dissimilar for no apparent reason.

III. Estimates of strength correlate negatively with performance.

Subject XX. Work Curves on Dynamometer.

A. Morning curves--11:00 a.m.

I. Mental work, class and studying.

Curves 1 and 2, dissimilar. Conditions constant. No apparent reasons for difference.

B. After dinner curve--12:30 p.m.

Curve 3, unlike either of morning curves. Rapid dropping off toward end.

C. Afternoon curves--3:00 p.m.

I. Physical work, hard work-out in football and basketball previously. Curves 4 and 6, somewhat similar--especially, short with rapid end drop. Conditions quite similar.

a. 4, basketball, estimate of strength 8.

b. 6, football, estimate of strength 4. In no case does subject's estimate of strength indicate anything relative to actual performance.

II. Mental work, botany laboratory.

Curve 5, unlike any other curve. Abnormally long. Conditions about same as in 1 and 2. Subject estimates strength as very weak.

D. Summary:

I. Most erratic performance of any individual.

II. Only those curves directly after hard physical work can be regarded as anything similar.

III. Subject's strength estimates do not coincide with performance.

Subject XXI. Work Curves on Dynamometer.

A. Morning curves--9:45 a.m.

I. Physical work, bicycling. Curves 1 and 2, unlike. Conditions not constant.

a. Curve 1, bicycling and half hour rest; less sleep than usual, but feels good.

b. Curve 2, bicycling against heavy wind. Plenty of sleep, but feels very much fatigued. Curve very much shorter and irregular.

B. Afternoon curves.

I. Early afternoon, 2:00 p.m.

Physical work. Curves 3 and 4. Curves more similar than are 1 and 2, but not the same.

a. 3, walking previously.

b. 4, bicycling previously; other conditions same as 3.

II. Late afternoon, 4:00 p.m.

Physical work--roller skating previously. Curve 5. Unlike curve 3 or 4. Conditions not same as 3 or 4. Curve shorter and more abrupt. Subject expresses feeling of fatigue.

C. Summary:

I. Curves erratic and unlike mostly because of heavy physical work beforehand.

II. In addition, subject was only boy in experiment, left-handed, and coordination for instrument not well developed.

Subject XXII. Work Curves on Dynamometer.

A. Morning curves--10:00 a.m.

I. Mental work, attends class previously.

Curves 1 - 5, not much similarity. Conditions constant except in curve 1.

a. Curve 1, less sleep than usual.

b. Estimates of strength do not coincide with production in any case.

B. After dinner curve--1:00 p.m.

Curve 6, very short curve, unlike any of the others.

C. Afternoon curves--2:00 p.m.

I. Mixed work, sewing and reading previously.

Curves 7 and 8, more alike than any other curves. Conditions not too constant.

D. Summary:

I. Curves can not be called similar except two in afternoon.

II. Daily routine by no means as constant as could be desired.

KEYS TO INDIVIDUAL CURVES

IN

ERGOGRAPH STUDY

Subject I. Work Curves on Ergograph.

A. Morning curves--12:00 noon (before dinner)

I. Physical work.

a. Curve 1, walking previously. Shortest curve of group. Subject feels weaker before this recording than she does before making curve 2.

b. Curve 2, bicycling previously. Conditions about same as curve 1 otherwise.

B. Afternoon curves--3:00 p.m. (curves 3 - 6)

I. Mental work, reading and writing previously. Curves 3, 5, and 6, quite similar. Conditions same except in 6. Much more sleep here, and curve 6 is longest of group. Curves not much different from morning curves, but early drop is steeper.

II. Physical work, walking previously. 1:15 p.m. Curve 4. Other conditions same as 3, 5, and 6. Curve approaches morning curves more nearly than those taken after mental work.

C. Summary:

I. Subject's curves very similar, and conditions quite constant.

II. Curves group according to type of work, mental or physical, previous to recording.

III. Warming-up period.

Subject II. Work Curves on Ergograph.

A. Morning curves--12 noon

I. Mixed work, laboratory routine.

Curves 1 - 5, similar. Conditions quite constant except night before curve 5--subject under hypnosis for demonstration purposes. Curve 5, however, follows curves almost point for point.

B. Afternoon curves--3:00 p.m.

I. Mixed work, laboratory routine.

Curves 6 - 9, similar except for 9. Conditions same for all. Curve 8 drops sharper than rest because of longer warming-up period. All curves much like morning. Curve 9 unlike any of the others for no apparent reason.

C. Summary:

I. All curves similar with one exception, but conditions constant.

II. Warming-up and steep end drops common.

<u>Subject VI</u>. Work Curves on Ergograph.

A. Morning curves--10:00 a.m.

I. Mental work, class previously.

Curves 1 - 3, very similar. Conditions constant.

B. After dinner curve--1:00 p.m.

Curve 4, similar to morning, but shorter and weaker. Other conditions constant except for time of day.

C. Afternoon curves. Curves 5 - 7.

I. Resting and smoking previously.

Curve 5. Curve like those of morning; however, subject has had much less sleep.

II. Physical work.

a. Curve 6, heavy carpentry. Curve has no usual warming-up, drops away rapidly but is longest of afternoon curves.

b. Curve 7, sharpening chisel. Curve similar to 5 and to morning curves.

D. Summary:

I. Curves quite similar. Conditions fairly constant except for type of work previously.

II. Hard physical work affects curve most.

III. Eating also has decided effect on length and strength of curve.

IV. Warming-up periods.

Subject VII. Work Curves on Ergograph.

A. Morning curves--11:30 a.m.

I. Mental work, correcting examinations previously.

Curves 1 - 4, similar, but curves 1 and 2 shorter than others with more steady decline. Conditions constant for all, however.

B. Afternoon curves--2:15 p.m. (Except Curve 5--3:00 p.m.)

I. Physical work, walking previously.

Curve 7, similar to other afternoon curves and also quite like those of morning. Other conditions same as curves 5, 6, and 8.

II. Mental work, correcting examinations.

Curves 5, 6, and 8, similar. Curve 6 shorter--late party night before, and dinner only half hour away. Otherwise conditions quite constant.

C. Special curve--11:30 a.m. (not included in average curve)

Curve 9. As subject was just ready to take record, the instructor brought a group of thirty visiting high school students into the laboratory. Curve begins much higher than any of others, drops away very rapidly, and is quite short.

D. Summary:

I. Curves quite similar, conditions fairly constant.

II. Eating close to record taking has effect of shortening curve.

III. Presence of large audience decidedly influences curve.

IV. Estimate of strength not apt to coincide with performance.

Subject X. Work Curves on Ergograph.

A. Morning Curves--9:15 a.m. (Except curve 3--10:30)

I. Mental work, teaching.

a. 1 and 2, similar, conditions constant.

b. 3, varies somewhat from above. Subject feels stronger. Curve likewise shows high initial contraction, then initial spurt and gradual decline with leveling off at end..

B. Afternoon curves--2:30 p.m.

I. Rest before records.

Curves 4 - 7, less similar to each other than morning curves, but follow somewhat same general trend. Curve 4 more level and curve 7 more steeply inclined than others. Conditions quite constant, however. Subject's estimate of strength fails to coincide with performance.

C. Summary:

I. Curves generally similar. Conditions fairly constant.

II. Initial spurt common.

Subject XI. Work Curves on Ergograph.

A. Morning curves--11:00 a.m.

I. Mental work, attends class.

a. Curves 1 and 3, not too similar. Conditions constant.

II. Physical work, walking.

a. Curve 2, very similar to curve 3. Other conditions constant.

B. Afternoon curves--time not constant.

I. Mental work. Curves 5, 6, and 7. Somewhat similar, but unlike morning curves.

a. Curve 5 (2:00 p.m.), writing previously.

b. Curve 6 (2:00 p.m.), class previously. Other conditions same as curve 5. (Steeper drop).

c. Curve 7 (3:15 p.m.), adding machine previously. Other conditions same as curve 5.

II. Physical work, turning mimeograph previously.

Curve 4 (2:45 p.m.), much higher than other afternoon curves. Quite irregular. Other conditions same as curve 5.

III. Rest previous.

Curve 8 (2:00 p.m.), longest curve. Unlike any of others. Very irregular. Other conditions same as 5.

C. Summary:

I. Curves fall in morning and afternoon groups.

II. Curves not apt to be too much alike, but have some general points in common.

III. Conditions not as constant as with some subjects.

IV. Warming-up effect.

Subject XII. Work Curves on Ergograph.

A. Morning curves--10:00 a.m.

I. Mental work, attends class.

a. Curves 1 - 4. In general, fairly similar. Conditions constant. Estimates of strength vary, but more often are not indicative of performance.

B. Afternoon curve. Time not constant.

I. Rest previous. Curve 5 (1:15 p.m.). Curve short and weak, but similar to curve 6 as well as to morning curves. Only 3 hours sleep the night before.

II. Mental work previous

a. Curve 6 (2:15 p.m.), adding machine previous. In general, similar to morning curves.

b. Curve 7 (2:15 p.m.), clinical work previously. Other conditions same as curve 6. Curve, however, much longer than curve 6; very irregular and unlike morning curves.

c. Curve 8 (4:15 p.m.), examination previous. Other conditions same as curve 6. Curve itself more like curve 7 but even much more irregular, especially in beginning.

C. Summary:

I. Curves tend to be similar except 7 and 8.

II. Time of day and activity previous to recording are important variables.

III. Lack of sleep, and examination period exert most disturbing influence.

IV. Estimates of strength do not coincide with performance.

Subject XIV. Work Curves on Ergograph.

A. Morning curves--9:45 a.m.

I. Mental work. Curves 1 - 4.

a. Curves 1 and 2, assembling test material. Curves dissimilar. Conditions same except in curve 2--much less sleep and rough-house the night before.

b. Curves 3 and 4, attends class. Conditions same as curve 1. Curves also similar to curve 1.

B. After dinner curve.--1:00 p.m.

Curve 5, similar to curves 3 and 4, but has slight warming-up period, more rapid drop and is shortest curve of group. Conditions otherwise same as in 3 and 4.

C. Afternoon curves--4:00 p.m. Somewhat similar.

I. Physical work, swimming. Curve 6, like morning curves but steeper drop and a bit more irregular.

II. Mental work, botany laboratory. Curve 7, like curve 6 except for high warming-up period. Other conditions same as 6.

D. Summary:

I. Curves generally similar.

II. Type of work influences curves slightly.

III. Curve after eating decidedly influenced by meal time.

Subject XV. Work Curves on Ergograph. (Left-handed)

A. Morning curves--12:00 noon.

I. Miscellaneous school work. Curves 1 - 3.

Curves similar. Conditions constant except for amount of sleep. Subject seldom gets much sleep, but this factor does not seem to influence work.

B. Afternoon curves.

I. Miscellaneous school work. Curves 4 - 6.

Curves very similar. Slightly different from morning curves. Conditions constant except sleep.

C. Summary:

I. Curves grouped according to morning and afternoon.

II. Each set of curves similar and conditions quite constant.

III. Warming-up effect.

Subject XVI. Work Curves on Ergograph.

A. Morning curves--9:30 a.m.

I. Mental work, study previous.

Curves 1 - 3, similar. Conditions same except for sleep. Curve 1 longer but not as strong. Only 4 1/2 hours sleep night before. As sleep and subject's estimate of strength increase in curves 2 and 3, curves get shorter in length but stronger.

B. Afternoon curves.

I. Office routine, stapling, adding machine, etc.

a. Curve 4, 3:00 p.m. Curve taken on same day as curve 1. Curve similar to morning curves, but very short and weak. This was day when subject had only 4 1/2 hours sleep night before.

b. Curves 5, 6, and 7. Curves similar to morning curves and very much alike. Conditions constant.

C. Summary:

I. Work curves similar.

II. Lack of sleep influences curve. Lack of sleep strengthened by low subjective estimate of strength.

III. Two curves in one day when there is little sleep night before greatly curtails performance on second curve even though 5 hours intervene between records.

Subject XVII. Work Curves on Ergograph.

A. Morning curves--10:30 a.m.

I. Mental work, writing. Curves 1 - 3.

a. Curves 2 and 3 similar. Curve 1 irregular. Conditions constant. No apparent reason for curve 1.

B. Afternoon curves--3:00 p.m.

I. Office work.

a. Curve 4, typing.

b. Curves 5, 6, and 7, reading and writing. Curves all alike and similar to curves 2 and 3 of morning.

C. Summary:

I. Curves very similar. Conditions constant.

II. Curve 1 irregular for no good reason.

III. Subject does not seem to become entirely exhausted. All curves drop to a point where constant level of performance is maintained indefinitely.

IV. All curves weak. Even maximum pulls are quite low.

Subject XVIII. Work Curves on Ergograph.

A. Morning curves---11:00 a.m.

I. Mental work, office hours.

Curves 1 - 4, similar except curve 4 which is more irregular and looks like afternoon curves. Conditions constant. Subject's strength estimate not at all indicative of performance.

B. Afternoon curves--4:00 p.m.

I. Mental work, study. Curves 5, 6, and 7, similar. Unlike morning curves in being more irregular.

a. Curve 6, sleepless night--does not seem to influence level of performance except for irregularity. Otherwise all conditions constant.

C. Summary:

I. Tendency to group according to morning and afternoon with afternoon curves more irregular.

II. Conditions quite constant.

<u>Subject XXII</u>. Work Curves on Ergograph.

A. Morning curves--10:00 a.m.

I. Mental work, class attendance. Curves 1 - 3, somewhat alike.

a. Curve 1, subject complains of cold and feverish condition. Curve more irregular than others.

b. Curve 2, subject feels stronger than usual. Curve starts high, but drops more rapidly. Shortest of the group.

c. Curve 3, Curve more level. Conditions same as curve 2.

B. Afternoon curves--2:15 p.m.

I. Mental work, class attendance.

Curves 4 and 6, not too similar. In fact afternoon curves more unlike than morning. Conditions not the same. More sleep, quieter evening and feels better in curve 6.

II. Physical work, walking. Curve 5, shorter and steeper than other afternoon curves. Conditions same as curve 6.

C. Summary:

I. Curves not too similar, but enough to exhibit general trends.

II. Subject's daily routine not as constant as most subjects.

III. Health sleep, and subjective estimate of strength influence curve.

## A C K N O W L E D G M E N T S

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